1980

The nutritional and physical characteristics of mechanically processed beef and pork product

Kenneth William McMillin
Iowa State University

McMillin, Kenneth William

THE NUTRITIONAL AND PHYSICAL CHARACTERISTICS OF MECHANICALLY PROCESSED BEEF AND PORK PRODUCT

Iowa State University Ph.D. 1980

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark ✓.

1. Glossy photographs ✓
2. Colored illustrations _____
3. Photographs with dark background ✓
4. Illustrations are poor copy _____
5. Print shows through as there is text on both sides of page _____
6. Indistinct, broken or small print on several pages _____ throughout _____
7. Tightly bound copy with print lost in spine _____
8. Computer printout pages with indistinct print _____
9. Page(s) _____ lacking when material received, and not available from school or author _____
10. Page(s) _____ seem to be missing in numbering only as text follows _____
11. Poor carbon copy _____
12. Not original copy, several pages with blurred type _____
13. Appendix pages are poor copy _____
14. Original copy with light type _____
15. Curling and wrinkled pages _____
16. Other _____

The nutritional and physical characteristics of mechanically processed beef and pork product

by

Kenneth William McMillin

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Department: Animal Science
Major: Meat Science

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1980

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEDICATION

TO

THE MEMORY

OF

MS. CAROL ANN McMILLIN

AND

DR. DAVID R. GRIFFITH

Their hard work, joy of learning,
and zest for life provided an
example and inspiration to all
who knew them.

INTRODUCTION

Nations in upward cycles of development, when the basic need to avoid famine has been satisfied, try to increase their supply of animal origin foods (Altschul, 1974). Increased agricultural development has accompanied the advancement of industry and technology. Improvement of meat supplies has been accomplished through genetic selection, greater production efficiencies, and nutrition and health advances. Development of a marketing system, inspection program, and transportation network have enabled meat processors to provide wholesome, palatable, and satisfying meat sources. Research has been responsible for the introduction of new technologies, processes, and products in the meat industry, as well as explaining the scientific principles which have been present in age-old practices.

Sausage products have their basis in early history as a means of preserving the highly perishable product of meat. Sausage makers have long formulated specific meats and spices to produce a characteristic product without understanding the chemical and physical processes involved. In the same manner, consumers accept certain products and reject others, often with no defined selection criteria. The purpose of this dissertation is to investigate the use of mechanically processed (species) product, commonly known as mechanically deboned meat, in meat emulsion products such as frankfurters.

Explanation of Dissertation Format

This dissertation is a modified form of the alternate thesis format permitted by the graduate college. A broad literature review

has been employed to explain the importance of mechanically processed (species) product and its uses in comminuted meat products. The formation of a stable sausage emulsion is a complex process and the background principles are essential in understanding the inclusion of mechanically processed (species) product into sausage products. For this reason, a brief description of meat emulsions and factors affecting meat emulsions also has been included in the literature review. The body of the dissertation is divided into four parts, corresponding to the four areas of research conducted and the four journal articles which will be submitted for publication. Part I is a study of the differences between control frankfurters and frankfurters containing progressive levels of mechanically processed (species) product. Chemical composition and physical traits of raw emulsions and frankfurters are examined in this section. There have been large discrepancies between reported results on factors influencing meat emulsion formation and stabilization depending upon the experimental conditions. In Part II, an emulsion preparation system using small batch sizes is compared to a commercial system utilizing larger emulsion batches. The physical characteristics and chemical composition of frankfurters are compared between machine type in this section. In addition, the influence of added water levels and temperature of chopping on emulsion stability are studied.

Many different deboning machines are available to produce mechanically processed (species) product and other factors such as type of bone, bone age, amount of lean adhering to the bone, and operating conditions affect composition of the deboned meat product.

Part III reports on the effect of different pressures to produce deboned meat in a KP Meat Removal System and the differences between sow and young pig bones, fresh versus frozen storage of bones, and swine bones compared to beef bones. Part IV examines the characteristics of mechanically processed (species) product produced by the KP Meat Removal System and a Yieldmaster deboner, influence of pork and beef bone age, and then compares deboned meat from the two machines and four bone types for nutritional value through a protein efficiency ratio assay using white rats as test animals.

Each part contains an introduction to briefly survey the literature, an experimental section to explain the methods and materials used, and a results and discussion segment to compare the results observed. A conclusions section follows the four research parts to summarize and link the research findings. Acknowledgements of contributions to this work, a bibliography of all references cited, and an appendix of useful but less pertinent tables for the study conclude this dissertation.

LITERATURE REVIEW

Protein Sources

Overpopulation is a subject of much concern to the world community. With the present population of 5 billion and an expected 7 billion people by the end of the century, there is a need to improve our methods for providing food to the consumer, particularly high protein foods (Fried, 1976). The food industry has responded to the need to provide more protein sources by investigating many new developments and technologies for extending meat supplies, including casava fermentation, trash fish proteins, microbial proteins, vegetable proteins, blood proteins, and mechanically deboned meat (Brown, 1975). Of these, cottonseed protein, fish meal, legume proteins, triticale, mechanically deboned meat, and single cell proteins are expected to experience much growth in the next ten years (Forsythe and Briskey, 1977).

The development of mechanical deboning of meat has been the most promising innovation in recent years of the methods which can extend our meat supply (Fried, 1976). The cost of producing meat is high and therefore it is important that as much protein as possible be recovered before the bones are rendered for nonfood uses (IFT Expert Panel, 1979). Estimates for increasing availability of meat proteins through deboning processes are 3 percent for pork and 4 percent for beef (Binkerd *et al.*, 1978) and millions of pounds of poultry meat have already been obtained by mechanical deboning procedures (Fried, 1976). Over 6,969,190 metric tons of bones each year could be made available for meat recovery, resulting in 2,090,757 metric tons of mechanically

deboned meat (MDM) on a world production basis (Field, 1976a). Mechanically deboned meat has met with wide acceptance in the United States although more information is needed to evaluate its qualities and acceptability (Fried, 1976).

The terms mechanically deboned meat, mechanically processed (species) product, and tissue from ground bone all refer to the same process of recovering meat tissues from animal bones by mechanical separation. Mechanical methods for removing meat from bones have been developed over the past 30 to 40 years because of the large amount of hand labor required to separate meat from bones. The first successful deboning machines were for fish, appearing in the late 1940's (IFT Expert Panel, 1979). Mechanical deboning of poultry meat began in the early 1960's (Noble, 1976) and now mechanical deboning has been developed to produce more edible tissue from red meat sources (Fried, 1976).

Types of Deboning Equipment

Mechanical deboning is a simple process where parts of the carcass or coarsely ground bones are forced against a screened or slotted surface. Muscle tissue passes through the openings as a finely comminuted product while most of the bone particles are shunted to one side (IFT Expert Panel, 1979). Two basic machine types exist. One type utilizes a rotary auger or moving belt to pass the bones across a sieve where the meat tissue and bone particles are separated. The second machine type utilizes a piston action to compress the bones. In this process, the bones contact one another and the meat is forced from the bones.

Several different models of deboning machines are available. The Bibun separator, built in Japan, is designed to produce coarse minced fish flesh. The meat passes between a crusher roller and perforated drum. As the drum revolves, a pressure belt forces the meat into the drum while the waste material is scraped from the outside. Operating capacity is 680 kg per hour. The Iwema machine, made in Sweden, feeds the bones into a screened drum where rotating lathes squeeze the meat product through the screen. This system is used mainly for vegetable pulping and the separation of fish and cod roe (Anonymous, 1975a). Another machine used in the processing of fish and which is less suitable for red meat and poultry is the Baader bone separator from West Germany. The operation is similar to the Bibun machine, where a belt conveys the material to a perforated drum. The meat is extruded through the perforations to the inside of the drum while the bones are removed from the external drum shell by a stripper plate (Anonymous, 1976).

The Prince World Mark V from Georgia uses a grinder to prebreak bones and pumps them directly to the infeed hopper. An auger transfers the particles forward, creating pressure that forces the meat through a drilled cylinder with small holes and the bone residue passes out the end. A popular deboner for the poultry and fish industry is made by the Stephen Paoli Manufacturing Corporation in Illinois. A previously ground mixture of meat and bone is fed onto a drum containing miniscule grooved openings. A pressure plate forces the soft material into these thin grooves while the waste product is scraped off. An auger then carries the deboned meat from the inside of the drum to

an outside chute for removal (Anonymous, 1975a). After previous grinding of the bones, a power auger forces meat through a stainless steel screen with conical holes in the Yieldmaster deboner, manufactured by the same company which produces the KP Meat Removal System. The bone waste is then carried to the end of the machine for removal (Anonymous, 1976). Beehive deboners, produced in Utah, also require prebreaking or grinding of the bones. A tapered auger in the housing transfers the meat forward to the deboning head. Backpressure created by the continuous flow forces the meat particles through the holes in the surrounding screen (Anonymous, 1975a).

Hydraulic pressure is used in the KP Meat Removal System which is manufactured in Iowa. A piston compacts the meat and bones into a hydrostatic mass and extrudes the meat from the compression cylinder through grooved concentric rings by the exertion of high pressure. The bone residue is ejected as a compressed mass. Another hydraulic deboner is made in the Netherlands and operates at a rate of 1090 kg per hour. The machine is called the Selo Bone Press and it has a hydraulic ram which compresses the bones, forcing soft tissue through filters. Both the KP and Selo machines are batch systems, while the other deboners operate on a continuous basis (Anonymous, 1976). In all of the above systems of deboning, increased pressure on the product against the sieving screen or plate causes more meat, but also more bone particles, to be removed from the bones (Field, 1976b).

Standards of Identity for Mechanically Deboned Meat

The United States Department of Agriculture must assure that deboned meat is wholesome, truthfully labeled, and unadulterated (Fried, 1976). Prior to 1976, meat was defined according to the source of the meat or meat product (Anonymous, 1975b). Since mechanically deboned meat (MDM) fit none of the six source categories, an interim regulation was drafted to allow production of MDM in 1976 (Federal Register, 1976a). Also, a proposed regulation to establish seven new categories for meat based on nutritional composition was introduced (Federal Register, 1976b). Consumer groups obtained an injunction prohibiting the use of MDM and so a select panel was convened by the USDA to assess health problems of MDM. The results of the select panel's findings (Kolbye et al., 1977) indicated that bone particle size from deboners currently available presented no hazards to health, slight nutritional benefits were expected for the calcium present, and fluoride, lead, cadmium, selenium, strontium-90, cobalt, copper, iron, nickel, zinc, arsenic, and mercury were of no health significance in relation to use of MDM. In addition, the panel also found no problem with chlorinated hydrocarbons, tetracyclines, microbiology, lipid spectra, or protein content and quality in conjunction with MDM.

As a result of the select panel's report, a revised proposal renamed mechanically deboned meat as "Tissue from Ground Bone," classified it as a meat food product, and limited it to 20 percent of the total meat content in processed meats. The product could not have a protein content lower than 14 percent and a fat content higher

than 30 percent. Also, the openings in the screens, sieves or parts used to prepare deboned meat could not be greater than 0.5 mm (Federal Register, 1977). After comments were gathered, the final rule was published (Federal Register, 1978), setting forth a definition, labeling requirements, and permitted uses for deboned red meat. Mechanically deboned meat was renamed Mechanically Processed (Species) Product or MP(S)P. Bones to be used for production of MP(S)P must be processed within one hour of being cut from the carcass or held no more than 72 hours at $4^{o}C$ or held indefinitely at $-18^{o}C$. MP(S)P must be used directly after being processed as an ingredient in a meat food product or can be held no more than 72 hours at $4^{o}C$ or indefinitely at $-18^{o}C$ before usage. At least 98 percent of the bone particles present in MP(S)P must have a maximum size of 0.5 mm in their largest dimension, and none of the bone particles are allowed to be larger than 0.85 mm. Maximum calcium content allowable is 0.75 percent, and the fat content must be less than 30 percent. Protein content must be at least 14 percent with a Protein Efficiency Ratio (PER) of 2.5, or an essential amino acid content of 33 percent of the total amino acids present, with isoleucine, leucine, lysine, methionine, phenylalanine, threonine, and valine considered as essential amino acids. Each establishment producing MP(S)P must have an approved quality control system and an approved written description of methods to insure product uniformity and conformance. The use of MP(S)P is limited to 20 percent of the meat portion of any meat food product such as chopped ham, fresh pork sausage, fresh beef sausage, breakfast sausage, whole hog sausage, Italian sausage, bologna, frankfurters, pizza toppings, liver sausage,

pressed hams, and similar products. When MP(S)P is used as an ingredient, the qualifying statement "contains up to ___% powdered bone" must be present on package labels. The use of MP(S)P may not be used in baby, junior, or toddler foods, ground beef, hamburger, fabricated steaks, barbequed meats, roast beef, corned beef cuts, beef with gravy, meat pies, lima beans with ham, and similar products (Federal Register, 1978).

Type and Yield of Bones

Deboning machines presently available are restricted to processing only flat, relatively soft beef bones, but all types of pork bones may be used (Goldstrand, 1975). Goldstrand (1975) also reported that 50 to 60 pounds of bones for deboning are available after hand boning beef carcasses, resulting in yields of 12.8 to 16.5 pounds of mechanically deboned meat (MDM). Beef neck bones produce the highest yields, accounting for 20 to 25 percent of the MDM recovered. Kelly et al. (1968) found that bone cleaned of all visible lean comprised 12.1 to 27.6 percent of the beef carcass weight. Price and Yeates (1969), feeding steers and bulls on high and low planes of nutrition, reported a range of 14.6 to 20.6 percent carcass bone. Field (1976a) found an average of 14.7 percent for bone percentage of market weight cattle and a value of 15.7 percent for market lambs. Ranges of 15.4 to 17.4 percent bone in lamb carcasses had been reported by Bell et al. (1967) and Munson et al. (1964). Kemp and Barton (1969) found that bone in lamb carcasses varied by grade (13.1 to 18.3 percent), while other researchers have also reported a range of 13.9 to 17.7 percent bone

in market weight lamb carcasses (Kemp et al., 1970; Field et al., 1967; Craddock et al., 1974; and Rouse et al., 1970).

Swine carcasses have a lower percentage of bone since larger amounts of backfat are present than on lamb and cattle carcasses (Field, 1976a). Bone percentages of 9.2 to 13.2 percent were reported in pork carcasses by Richmond and Berg (1971) and bone accounted for 9.5 percent of the carcass for market weight swine in studies by Cuthbertson and Pomeroy (1962) and 11.3 percent of the carcass in a report by Brooks et al. (1964). Bone accounts for a higher percentage of the carcass when the wholesale cuts are boned under commercial conditions than when carcasses are hand cleaned under laboratory conditions (Field, 1976a). Field (1975) found that sow loin bones contained 46.7 percent of their weight as lean, ham bones 25.1 percent, picnic bones 18.1 percent, and Boston butt bones 18.7 percent as lean. Beef neck bones possessed 41.3 percent of their weight as lean, rib bones 26.2 percent, rump bones 18.1 percent, and shortloin bones 25.6 percent. Field (1976a) concluded that 20 percent of the beef, lamb, and pork carcass weight was bone when the boning process took place under commercial conditions.

Goldstrand (1975) reported 58.5 pounds of bone per beef carcass with the following distribution: neck bones, 10 pounds; chine bones, 2.5 pounds; loin bones, 11 pounds; chuck-rib bones, 9 pounds; rib rack bones, 12 pounds; and the plate bones, 14 pounds. These bones gave a yield of deboned meat of 30 to 40 percent for the neck and chine bones, 20 to 30 percent for the loin and chuck-rib bones, and 18 to 24 percent for the rib and plate bones. He also reported that pork carcasses

contain 1 pound of neck, 1.6 pounds of back, 1 pound of blade, 5.2 pounds of ham, and 3.2 pounds of picnic bones. The neck bones yielded 30 to 50 percent MDM, back bones 40 to 50 percent, and the blade, ham, and picnic bones 22 to 30 percent deboned meat. According to Field (1976a), bones from the vertebral column, ribs, and sternum are most suited for deboning by machine, since more lean is attached and bone marrow contributes to MDM yields. He concluded that these bones comprise about 10 percent of the carcass weight. The ox coxae are the second most suitable bones for mechanical deboning. The round bones, such as the femur and humerus, are the least desirable for machine deboning because they have little lean attached and the marrow is mainly comprised of fat (Field, 1976a).

Field and Riley (1975) reported the femur bone marrow in cattle was approximately 92 percent fat, while femur marrow in calves was 33.7 percent fat. Gong and Arnold (1965) had previously reported higher concentrations of fat and lower protein content in the adult bone marrow for the femur, tibia, fibula, and pelvic girdle. Increases in fat and dry matter of bone increased with animal age for red meat species, but fat remained constant while dry matter of bone increased with age in poultry (Field *et al.*, 1974c). As animals grow and develop, bone content increases in ash with a major increase in calcium (Field and Riley, 1975). Maynard and Loosli (1979) stated that bone ash from mammals contains 36 percent calcium, 17 percent phosphorus, 0.8 percent magnesium, and smaller amounts of other minerals. These values agree closely with those reported by Field *et al.* (1974c).

Yields from Machine Versus Hand Boning

Field et al. (1975) found that for every bone source compared, yield of MDM was higher than yields obtained by hand boning. The MDM contained bone marrow, lean and also some bone particles less than 0.46 mm in diameter. These particles came through the Beehive deboner equipped with 0.46 mm holes in the cylinder. In the Field et al. (1975) study, increases in yield from mechanical deboning over hand boning ranged from 2.1 percent for choice beef plates to 23.8 percent for veal frames. The bone marrow extracted as deboned meat and the connective tissue removed by deboning caused higher yields, higher fat, and lower protein percentages in MDM as compared to hand boned meat from veal, beef, and pork bones. Field et al. (1975) also found that veal back frame bones and sow loin bones, which had the most lean adhering to them, yielded more protein in the MDM than other bones (ham, picnic, Boston butt bones in pork and rump, shortloin, and plate bones in beef) where more protein was discarded with the bone residue than was recovered from the bone marrow. Goldstrand (1975) also reported that bones with more lean attached, neck and back bones, for example, would produce greater yields and lower calcium levels than bones with little lean attached to them, such as pork ham and picnic bones, when mechanically deboned after commercial hand boning.

Field (1974) had previously reported that intact lamb breasts from one lamb carcass side contained 10 percent bone when physically separated, but lamb breasts from the other carcass side which were mechanically deboned resulted in a yield of 78.7 percent MDM.

Broiler necks were compared in that study, and 14.5 percent bone was obtained by hand boning, but similar broiler necks yielded 60 percent MDM when machine deboned. Neck and back bones of barrows and gilts yielded 30 to 40 percent MDM after they had been commercially boned. Anderson and Gillett (1974) reported higher ash and fat contents for MDM than for meat from hand boned mutton carcasses. The breast yielded 41 percent MDM; the back, 65 percent; the leg, 67 percent; and the shoulder, 57 percent MDM for an overall yield of 57 percent MDM of the total carcass weight in that study.

Field et al. (1974b) used good and utility grade mutton carcasses to determine the difference between yields of cold and hot boned carcasses. Hand boning by physical separation resulted in 18.33 percent bone, while a Beehive deboner with 0.635 mm holes in the cylinder passed through 23.81 percent bone to be discarded when carcasses were processed cold. Hot processing before the development of rigor mortis gave 17.36 percent bone by physical separation and 17.98 percent discarded bone with mechanical deboning. They reported no difference between hand boned meat and MDM for fat, protein, and dry matter percentages, whether the carcasses were processed hot or cold. The MDM was slightly lower in protein content than hand separated meat because tendon connective tissue was discarded with the bone residue during mechanical deboning (Field et al., 1974b).

Chant et al. (1977) reported that lean and fat scraped from good and choice grade beef carcass flat bones obtained after commercial boning comprised 34.3 percent of the total bone weight. Comparable bones

yielded 30.1 percent MDM when processed through a Beehive deboner with 0.46 mm openings in the cylinder in that study.

Chemical Composition of MDM

Yield influence

Meat processors would like to increase yields of MDM as much as possible because it is a low cost protein source (Goldstrand, 1975). Increased yields cause differences in MDM composition, however. Field et al. (1974a) found that percentages of bone, fat, and calcium in MDM were directly related to yields obtained when mutton carcasses and lamb carcass parts were deboned. The ring value of the Beehive deboner (cylinder with 0.635 mm diameter holes) was adjusted during different trials to cause yields of MDM from mutton carcasses to vary. When a yield of 52 percent MDM was obtained, calcium content was 0.09 percent and fat was 8.62 percent in the MDM. In another trial, a yield of 70 percent caused the MDM to increase to 0.20 percent calcium and 17.10 percent fat. Maximal yield obtained was 84 percent and the MDM contained 0.27 percent calcium and 24.93 percent fat. Bones similar to those in the above deboning trials contained 21.27 percent, 18.3 percent, and 17.19 percent bone when all lean and fat were removed by physical separation. Similar data were reported for lamb necks, shoulders, breasts, and legs. The authors concluded that some bone particles, calcium, and fat from the bone were forced into the MDM at higher yield settings. Type of bone and maturity of bone also influenced the composition of MDM (Field et al., 1974a).

Bone preparation

Preparation of bones prior to deboning also directly influences MDM composition. Goldstrand (1975) found that the bone coarseness from grinding prior to deboning had a direct relationship to the percentage of calcium in MDM. Increasing the grind size from 0.95 mm to 1.91 cm resulted in a 50 percent reduction in calcium obtained in MDM from pork ham, picnic, back, and neck bones. Prebreaking of the bones instead of grinding through a 1.91 cm plate resulted in another 50 percent reduction in calcium levels in MDM for pork neck, ham, and picnic bones.

Deboner influence

Both Goldstrand (1975) and Field (1974a) found that reducing the head size or strainer opening size would cause less bone particles and calcium to be present in the MDM. Goldstrand (1975) also reported that the type of deboning machine utilized was a major factor in control of calcium levels in MDM. He tested two continuous or rotary machines and one deboner which used hydraulic pressure for separation, but did not identify brand names of the deboners used. The straining devices varied. All machines produced MDM which contained less calcium than the USDA allows when pork neck and back bones were deboned. However, he found only one of the continuous machines produced MDM which would meet calcium requirements when picnic and ham bones were processed by deboning. The pork necks and backs produced MDM which ranged from 13.3 to 15.6 percent protein, 24.7 to 35.7 percent fat, and 50.8 to 60.3 percent moisture. Ham and picnic bones produced MDM which did

not meet USDA requirements, with 9.4 to 12.5 percent protein, 35.8 to 41.1 percent fat, and 44.1 to 51.5 percent moisture being present in the MDM.

Other influences

Goldstrand (1975) also diluted ham bones with whole skinned picnics and mechanically deboned the mix. He found the MDM produced did not meet protein and fat requirements and concluded the sole alternative to bring the fat and protein levels into compliance was to increase the lean content on the bones which would be mechanically separated. Grunden et al. (1972) had previously studied deboned meat from poultry sources. Broiler backs and necks and turkey racks produced MDM with 12.8 percent or less protein. Spent layer carcasses resulted in MDM with 14.2 percent protein, but all samples of MDM tested contained less than 27.2 percent total lipid. Satterlee et al. (1971) had previously shown that leaving the skin attached to chicken broiler backs caused higher fat and lower protein content of MDM than when skin was removed prior to deboning. The collagen present in the skin was removed along with the bone, but fat in the skin passed into the MDM during deboning.

Quality of MDM

Bone particle size

Bone particle size in MDM has been of interest because there is a maximum size of 0.85 mm permitted (Federal Register, 1978). Field et al. (1977) measured bone particles isolated from MDM by papain

digestion and carbon tetrachloride:acetone separation. They found that the percentage of bone forced through the Beehive deboner equipped with 0.46 mm openings in the cylinder ranged from 2.8 to 4.1 percent. Size of the particles ranged from 10 microns to 450 microns, with an average size of 76.6 to 111.7 microns. Froning (1979) determined that hand boned sources of turkey meat contained larger bone particles than MDM produced by a Beehive deboner. Equipped with a 0.80 mm screen size, the deboner produced amorphous bone particles with an average diameter of 233 microns. Grunden and MacNeil (1973) earlier had found MDM from turkey racks, broiler necks and backs, and spent layer carcasses to have 0.55, 0.79, and 1.21 percent bone, respectively.

Color traits

Considerations other than calcium, bone particles, protein, and fat content influence the quality and acceptability of MDM. The color of MDM is important since MDM would replace higher value meats. Goldstrand (1975) discovered that MDM had a 25 to 30 percent higher color level than pork and beef trimmings of similar protein and fat levels. Chant et al. (1977) learned that MDM had a total pigment concentration of 10.16 mM/ml. Kunsman et al. (1978) determined that MDM from beef flat and neck bones contained 6.4 mg/g heme pigment, while ground beef with a similar fat percentage contained 3.7 mg/g heme pigment. For the MDM from flat and neck bones, hemoglobin comprised 85 percent and 54 percent of the total pigment and myoglobin accounted for the rest of the heme pigments, but myoglobin accounted for 72 percent of the total heme pigment in the ground beef.

Grunden et al. (1972) found that turkey racks produced MDM with a redder color than MDM from chicken backs and carcasses, since turkey muscle generally contains more myoglobin than chicken muscle.

Fatty acid characteristics

Lee et al. (1975) suggested that increased quantities of heme pigments in MDM may cause problems of oxidation in the deboned product. Polyunsaturated fatty acid:heme ratios for mechanically deboned chicken were 480:1. This is just at the maximum level for pro-oxidant activity. Moerck and Ball (1974) found higher concentrations of polyunsaturated fatty acids of the phospholipids present in MDM from chicken. Kunsman and Field (1973) measured hydrolysis and oxidation of lamb fat during deboning and concluded no differences existed in the free fatty acid content of MDM and hand boned lamb breasts and little oxidation occurred due to the deboning process. Kunsman et al. (1978) used fresh beef neck and flat bones to study lipid oxidation in MDM. No difference in disappearance of polyunsaturated fatty acids was found between MDM and ground beef, and there was no difference between monocarbonyl content of MDM and ground beef, leading the researchers to conclude that lipids from MDM beef bones oxidized at the same rate as lipids in ground beef. Goldstrand (1975) had previously measured TBA values, an indication of oxidative rancidity, in mechanically deboned pork and beef. The TBA numbers were slightly higher than usually experienced in pork and beef trimmings, but 57 percent of the pork and 75 percent of the beef samples had TBA values less than 2.0. Field (1976b) stated that MDM from red meat sources would behave

differently in storage than MDM from poultry sources, where lipid oxidation occurred.

Microbiological traits

Microbiological quality of MDM can be a problem if bones are not kept cold and processed immediately upon removal from the carcass. Ostovar et al. (1971) reported higher total aerobic counts in mechanically deboned chicken over conventionally processed chicken. Maxcy et al. (1973) observed microbial counts of 100,000 to one million per gram and coliform counts of 10 to 1,000 per gram in deboned chicken meat. Field et al. (1974b) reported no significant difference in bacterial loads between hand boned and machine deboned mutton carcass meat for either hot or cold processing. Goldstrand (1975) showed that aerobic plate counts of 100,000 counts per gram or less were obtained for 87 percent of the pork samples and 45 percent of the beef samples used in the study. All samples were less than one million counts per gram. Strict limitations on time of processing, temperature of samples, and storage conditions (Federal Register, 1978) would appear to control microbial growth in MDM.

Nutritional Evaluation of Deboned Meat

Mineral and vitamin levels

Concern has been expressed over the safety and health of MDM for human consumption (Federal Register, 1978). Doyle (1979) completed a review of toxic and essential elements in bone. There is a lack of knowledge on concentration of arsenic, cadmium, lead, and mercury in

bones, but there seem to be no problems with the public consuming bone meal and MDM, since data which are available suggest low bone concentrations of these elements. Fluoride concentration in bone ranges from 100 to 600 mg/g dry, fat-free tissue. Kruggel and Field (1977) measured 9.83 to 16.21 μg/gm fluoride in beef MDM and 7.62 μg/g fluoride in pork MDM. Kolbye et al. (1977) concluded the additional fluoride was easily handled by people with normal kidney functions. Calcium, magnesium, and phosphorus concentrations in the mineral portion of bone are high, 36 percent, 0.8 percent, and 17 percent, respectively (Maynard and Loosli, 1979).

Kruggel and Field (1977) found these minerals to be 0.39 percent to 0.50 percent for calcium and 15.57 mg/100 g to 18.85 mg/100 g for magnesium in MDM. Values of 1.72 percent calcium and 30 μg/100 g magnesium were reported by Chant et al. (1977) for beef deboned meat. Doyle (1979) stated that calcium, phosphorus, and magnesium are diluted in MDM and were of no toxic significance. Concentrations of selenium, zinc, copper, manganese, and iron were found to be very low in the previous review, and the ingestion of MDM would not add substantially to the intake of these elements normally consumed. Kruggel and Field (1977) reported concentrations of 3.78 to 6.30 mg/100 g iron in MDM. Farmer et al. (1977) studied the iron bioavailability of hand and mechanically deboned beef. Iron content was higher for MDM (44 and 93 mg/kg dry matter) than for hand deboned plate and shank meat (37 and 52 mg/kg dry matter), but the iron from hand boned beef was better utilized than iron from MDM by the anemic rats. The presence of additional calcium and hemoglobin iron in MDM may be of nutritional benefit to

humans, however (IFT Expert Panel, 1979). Many nutritionists consider U.S. diets to be deficient in calcium (Walker, 1972; Lutwak, 1974), and the bioavailability of calcium from bone and milk are similar (Mitchell, 1964). Hemoglobin iron has been shown to have good availability when consumed by humans (Martinez-Torres et al., 1974).

Ascorbic acid is lacking in hand boned meat (Watt and Merrill, 1963), but is high in bone marrow at a level of 24 mg per 100 gm of tissue (Lutwak-Mann, 1952). Field (1976a) stated the amount of ascorbic acid in MDM was dependent on freshness of the bones used for deboning, but some destruction of ascorbic acid can also occur during the deboning process. Kruggel and Field (1977) reported 2.08 to 2.67 μg ascorbic acid per 100 grams of mechanically deboned beef and pork. Chant et al. (1977) found only 1.37 μg ascorbic acid per 100 grams of mechanically deboned beef. Mechanically deboned meat produced from bones obtained from cured pork cuts contained 12 to 16 mg ascorbic acid per 100 grams of tissue because ascorbic acid was included as a curing ingredient (Field, 1976).

Connective tissue protein

Since the primary usage of MDM will be to replace meat tissue in processed meat products, the protein quality of MDM is of concern for human nutrition. Hydroxyproline, an indicator of connective tissue, has been shown to be higher in hand boned lamb breasts than in MDM from lamb breasts (Field and Riley, 1974). Much of the connective tissue was removed by mechanical deboning.

Field et al. (1974b) measured less hydroxyproline in MDM than in hand boned mutton carcasses. Dvorak (1972) reported a high negative relationship existed between net protein utilization by animals and the amount of hydroxyproline in meat. This indicates that less hydroxyproline results in an increased protein nutritional value. Gillett et al. (1976) found that wholesale hand boned beef cuts contained 0.36 to 0.57 percent hydroxyproline and pork shoulders 0.25 percent hydroxyproline, resulting in 2.95 to 4.58 percent connective tissue in the beef cuts and 1.98 percent connective tissue in the pork shoulders. By using a desinewing head on a Beehive deboner, hydroxyproline was reduced to 0.20 percent, and the connective tissue reduced to 1.56 percent. Chang and Field (1977) measured nine different MDM samples for collagen content and found a range of 6.00 to 16.49 percent collagen present. The MDM with more lean and less collagen was superior in protein quality to MDM with less lean and more collagen connective tissue.

Amino acid content

Another method to evaluate protein quality is to measure the eight essential amino acids (isoleucine, leucine, lysine, methionine, tryptophan, threonine, phenylalanine, and valine). Skeletal muscle protein contains the eight essential amino acids in proportions adequate to meet the dietary needs of humans (Binkerd et al., 1978). Goldstrand (1975) reported that 34 to 42 percent of the total proteins in MDM are comprised of the eight essential amino acids. Field (1976b) indicated the eight essential amino acids comprised 34 to 37 percent of the total

amino acids for meat from hand scraped bones. Chant et al. (1977) found only the level of isoleucine was significantly higher in MDM than in mechanically separated (desinewed) tissue. No differences were found in nonessential amino acids, although slightly lower levels of glycine, proline, and alanine, which indicate collagen presence, were found in MDM. Chang and Field (1977) reported a range of 46.75 to 58.40 percent essential amino acids of total amino acids for various MDM samples, which compared to 58.11 percent essential amino acids in the lactalbumin standard. Hendricks et al. (1977) compared mechanically desinewed meat to hand deboned meat and found a slightly higher essential amino acid to total amino acid ratios in the mechanically desinewed meat. Field et al. (1979) found the amino acid composition for mechanically processed beef and pork product to be similar to that for hand boned meat characterized by Happich et al. (1975) at 39 to 40 percent essential amino acids when compared to the total amino acids present. MacNeil et al. (1979) reported 37.49 to 38.26 percent essential amino acids per total amino acid residues in mechanically deboned turkey meat. Essary and Ritchey (1968) had previously characterized the amino acid composition of deboned turkey meat and found it similar to chicken, pork, and beef skeletal muscle, milk, and eggs in amino acids.

Protein efficiency ratios

Two commonly used methods to determine protein and amino acid utilization by animals are nitrogen balance (biological value and net protein utilization) studies and growth assays where the gain in weight of test rats is reported as protein efficiency ratio (PER)

(Binkerd et al., 1978). The USDA has set a PER of 2.5 as the minimum protein quality for MDM, or alternatively to have 33 percent of the total amino acids as essential amino acids (Federal Register, 1978). Alsmeyer et al. (1974) attempted to predict PER from amino acid composition and found a PER of 2.85 for beef and an estimated PER of 2.90. Happich et al. (1975) reported a PER value of 2.85 for lean hand boned beef. PER values for various samples of MDM ranged from -.55 for MDM produced by scraping all lean from bones prior to deboning to 2.69 for deboned lamb rib cages and .39 for beef trim and 3.63 for lactalbumin in a study by Chang and Field (1977). Since PER values are a function of weight gain, take into account no protein for maintenance, and underestimate the best quality proteins, the slope-ratio assay is more indicative of protein quality (Hegsted, 1977). Chang and Field (1977) found relative nutritional values of 19.90 for MDM produced after bones had been scraped of all lean to 68.00 for MDM from lamb rib cages, compared to 24.30 for beef trim and 100.00 for lactalbumin. Hendricks et al. (1977) reported PER values of 3.9 for desinewed shank meat compared to 3.5 for shank meat and 2.9 for casein. However, they indicated there was a discrepancy between PER and nitrogen efficiency for growth (NEG) values and net protein utilization (NPU) and biological value (BV) determinations when urinary losses were not accounted for by PER and NEG. Lee et al. (1978) attempted to predict PER from the chemical analysis of connective tissue content in meat. They found 85 percent beef trim had a PER of 2.96, MDM had a PER range of 2.54 to 2.83, and chicken MDM from chicken carcasses had a PER of 3.01 compared to hand boned chicken meat with a 3.13 PER. They also

reported correlation coefficients of -.99 between the collagen content and essential amino acid content and -.98 between collagen and rat PER. Field et al. (1979) studied various mechanically processed (species) products and found ranges of PER from 1.44 for cow rib bones to 2.90 for lamb neck bones compared to 2.97 for a casein control group of rats and 2.91 for beef semimembranosus muscle. Brinkman and MacNeil (1976) reported unadjusted PER values of 3.6 for hand boned and 3.7 for mechanically deboned broiler neck meat. Later, an adjusted PER of 2.65 for mechanically deboned broiler meat was reported (MacNeil et al., 1978). When mechanically deboned meat from turkey breasts, racks, and backs were fed to rats, PER values of 2.92, 3.09, and 3.05 were found, respectively, for the deboned turkey samples, compared to 2.65 for broiler necks and 2.50 for a control casein diet. From the previous studies, it appears MDM is acceptable from a health standpoint and it is comparable to hand boned meat nutritionally.

Mechanically Deboned Meat in Processed Meat Products

Emulsion type products

Mechanically deboned poultry meat is suitable for combination with other meat to produce emulsion type meat products (Pauly, 1967). Mechanically deboned raw meat is produced in the form of a paste and is very adaptable to emulsified products (Froning, 1970). Since mechanical deboning may cause cellular disruption, protein denaturation, and increased heme and lipid oxidation (Froning, 1976), considerable research activity has centered on areas of processing and sensory characteristics of MDM (Berry, 1978). Froning (1970) compared hand

deboned white and dark chicken meat, Paoli machine deboned chicken backs and necks and turkey frames, and Beehive deboned chicken backs for emulsification properties. Mechanically deboned meat sources were most stable when chopped in a silent cutter to temperatures of 7.2 to 12.8°C. Tensile strengths of finished emulsions decreased and amounts of fat and gel-water released during processing increased at temperatures above 12.8°C. Hand boned broiler meat was stable in emulsions at all chopping temperatures. Photomicrographs of emulsions showed MDM sources had less protein matrix available for emulsion formation than hand deboned meat sources, due to greater collagen dispersion and possible loss of protein solubility caused by deboner protein denaturation. Froning et al. (1971) utilized a level of 15 percent mechanically deboned turkey meat in red meat frankfurters to study stability and acceptability of this product. The mechanically deboned turkey meat (MDTM) produced with a Paoli deboning machine showed a greater capacity to emulsify oil per 2.5 g sample than pork trimmings but less capacity than boneless cow meat. Also, MDTM exhibited less water holding capacity than the red meat sources. More gel-water loss was exhibited by frankfurters containing 15 percent MDTM but frankfurters which contained fresh MDTM had less cook loss than control frankfurters or franks containing MDTM which had been stored frozen for seven days prior to use. No significant differences between control frankfurters and frankfurters containing the frozen MDTM were found in triangle or preference sensory tests by a flavor panel while frankfurters containing 15 percent fresh MDTM were scored lower ($p < .01$). TBA values were much greater for fresh

MDTM in frankfurters than for the other two types of frankfurters tested, explaining the preference scores of the flavor panel. Small, unnoticeable differences between frankfurter types were found for color evaluation and microbial counts. Schnell et al. (1973) compared mechanically deboned poultry meat (MDPM) with hand boned carcass meat and found a firmer frankfurter was produced using the hand boned carcass meat. As size of screen to produce the MDPM increased, tenderness, flavor, and acceptability of frankfurters decreased. With 0.05 cm screen openings, no significant differences between control and MDPM frankfurters were noted for flavor and acceptability. No large differences in stability of frankfurters were found between treatments in this study, although Froning and Janky (1971) had previously thought use of higher salt levels or pH adjustment would improve the stability of MDM sources in emulsion products. Baker et al. (1974) utilized MDPM from three machines to measure the effect of chopping time on taste panel evaluation and frankfurter stability. Chopping time had little effect on results of these tests, but source of the MDPM caused differences in frankfurter yield, stability during cooking, emulsion viscosity, and taste panel scores of texture and juiciness. More dense MDPM and smaller, more evenly distributed fat globules contributed to the stability of frankfurters with two of the MDPM sources as compared to the third MDPM source (Angel et al., 1974).

Field et al. (1974b) prepared bologna with MDM from lamb cuts and mutton carcasses. With larger sized holes in the Beehive deboning cylinder (1.016 mm and 0.787 mm), grittiness was readily detected due to the presence of bone particles. When MDM from a cylinder with

0.635 mm holes was compared with hand boned meat in the bologna, 12 of the 17 taste panel members who were able to detect a difference preferred hand boned mutton over 100 percent machine deboned mutton. However, seven of 12 members who detected a difference between hand boned mutton and a level of 50 percent MDM in the bologna preferred the machine deboned bologna. Field et al. (1974a) concluded that at least 15 percent MDM could be incorporated into an emulsified product without any detrimental effect on flavor or texture. They found bologna made with 100 percent MDM was not objectionable, but this product had different organoleptic traits than bologna made with hand boned meat. No differences in TBA values, texture, or processing shrink were measured between bologna made with hand boned mutton or machine deboned mutton, but the MDM bologna had greater emulsion stability, more total pigments, and a brighter subjective color than the control bologna. Baker and Darfler (1975) used mechanically deboned turkey racks to produce frankfurters. With increased levels of MDM as the protein source, taste panel scores for tenderness and juiciness decreased, but flavor scores remained the same for all levels of MDM. Emulsion stability and yield increased with higher levels of MDM in the frankfurter mixes. Meiburg et al. (1976) produced frankfurters containing MDM from whole cow, sow, and mutton carcasses and pork neck bones. They found that frankfurters with greater than 40 percent cow MDM or 20 percent pork neck bone and mutton MDM had unacceptable flavor. Frozen storage of MDM before usage caused decreased taste panel scores for frankfurters made with sow MDM but not for cow or mutton MDM. Storage time of frozen MDM caused no reduction in emulsifying capacity

or pigment content of MDM, but an excessively dark frankfurter color was observed when high levels of cow MDM were used. Marshall et al. (1977) used MDM from old and young goats, mutton, and pork at levels of 10, 25, or 40 percent in frankfurters. Frankfurters with goat or mutton MDM were similar to control frankfurters for processing characteristics, while frankfurters with 25 or 40 percent MDM from pork bones were very susceptible to physical deformation. With increased levels of MDM from all sources, smokehouse yield of frankfurters decreased. Frankfurters with goat or mutton MDM were found equal or superior in flavor, juiciness, and texture to control frankfurters by a sensory panel. Frankfurters with 25 or 40 percent pork MDM were significantly ($p < .05$) inferior in juiciness and texture than other batches of frankfurters. No differences in flavor between bologna made with hand boned beef and 30 percent MDM were reported (Chant et al., 1977), but bologna with the 30 percent MDM was judged to be gritty and less preferred by taste panelists. Misock et al. (1979) manufactured bologna and replaced 20 percent of the lean beef with 20 percent MDM. Both the control and 20 percent MDM bologna had decreased flavor scores as storage time increased. Flavor scores and fatty acid profiles were similar for both bologna types at each storage period tested. Misock et al. (1979) concluded that bologna containing MDM had no greater oxidation rates than the control bologna.

Coarse ground sausage

Mechanically deboned meat has also been tested in meat products other than emulsion-type sausages such as bologna and frankfurters.

Dhillon and Maurer (1975a) utilized mechanically deboned chicken meat (MDCM) in summer sausage. Summer sausage made of 100 percent MDCM had a lower shear press value, increased sliceability, greater smokehouse loss, and lower sensory evaluations of texture, color, and appearance than summer sausage made from all beef or 100 percent hand boned chicken meat. Inclusion of MDCM into summer sausage formulations enhanced the cured color development; however, combinations of MDCM and ground beef containing up to 50 percent MDCM resulted in an acceptable product with good color, firmness, and texture. When summer sausage formulated with 50 percent MDCM/50 percent beef, 50 percent mechanically deboned turkey meat (MDTM)/50 percent beef, and 100 percent beef were produced, harder texture, darker color, and higher overall appearance and acceptability scores by sensory panels were found for the 100 percent beef summer sausage (Dhillon and Maurer, 1975b). The 100 percent beef summer sausage also had a higher shear value and less sliceability due to the higher protein levels present than in the formulations containing MDCM or MDTM.

When Joseph et al. (1978) used mechanically deboned beef in cooked salami, less desirable flavor, juiciness, tenderness, and texture scores were recorded for salami which contained 20 and 30 percent MDM. In that study, flavor profile panels identified higher aroma and flavor intensities and more rancid flavors as the level of MDM and the length of storage time increased, but 10 and 20 percent substitution levels of MDM into cooked salami could successfully be employed. Mechanically processed beef product had also been incorporated into dry fermented salami at 15 and 30 percent levels with acceptable

results (Berry et al., 1979). Use of MDM in combination with structured soy protein fiber resulted in undesirable flavor, color, texture, and tenderness in the salami.

Fresh manufactured meat products

Several studies have been conducted on the inclusion of mechanically deboned meat into ground beef, but this product is not currently allowed for consumer sales (Federal Register, 1978). Cross et al. (1977) found that cooked ground beef patties containing levels of deboned beef at 20 percent and below were more acceptable than control patties. As the percentage of MDM in patties increased, panel ratings for tenderness and juiciness decreased and ratings for detectable connective tissue and flavor decreased. Seideman et al. (1977) used mechanically deboned beef and textured soy protein in ground beef formulations. Patties which contained 10 or 20 percent MDM were darker in color and finer in texture than control patties, and also lost less fat during cooking. Patties containing the textured soy protein or combinations of MDM and textured soy protein at a greater than 10 percent level were less desirable in flavor, palatability, and texture.

Microbiological evaluation of frozen ground beef containing mechanically deboned beef revealed that levels of MDM to 30 percent could be used without affecting shelf-life (Emswiler et al., 1978). Cross et al. (1978a) found that ground beef containing 0, 10, or 20 percent mechanically deboned beef had no different properties under frozen storage than control ground beef containing no MDM. Level of deboned beef was found to significantly ($p < .01$) influence taste

evaluations for tenderness, juiciness, flavor, connective tissue, appearance, aroma, and desirability. The TBA values for all formulations were well below the values corresponding to oxidative rancidity.

Mechanically desinewed meat

Hand boned meat passed through a mechanical deboner to remove connective tissue is called mechanically desinewed meat (Berry, 1978). Chant et al. (1977) used desinewed meat and MDM to manufacture bologna and reported a significant ($p < .01$) improvement in flavor and less grittiness in bologna made with the 30 percent desinewed meat. Mechanically desinewed tissue had previously been shown to remove one-half of the connective tissue, decrease fat, increase cooking yields, and increase the tenderness and texture of cooked salami (Gillett et al., 1976).

Cross et al. (1978b) found that desinewed beef improved the textural properties of beef patties, particularly when meat from mature animals was desinewed. A 0.19 cm desinewing head was considered superior to the 0.25 and 0.32 cm heads for removing connective tissue with the Beehive machine.

Meat Emulsion Technology

Emulsion theory

An emulsion is often defined as a dispersion of small droplets of one immiscible liquid in another liquid (Becher, 1965). An emulsifying agent must be present at the interface of the suspended droplets (the dispersed or internal phase) and the suspending medium (the

continuous or external phase) (Mittal, 1971). Most emulsions involve water and oil or fat as the two immiscible phases (Petrowski, 1976). The degree of dispersion is the result of two opposing tendencies, the disruption of globules due to impact disintegration and shearing forces, and the tendency for globules to coalesce on contact (Stamm and Kramer, 1926). Repulsive electrostatic forces tend to keep the droplets separated, but other mechanical or physical properties prevent the coalescence of droplets (Petrowski, 1976). The tendency for the droplets to coalesce is influenced by the interfacial tension, volume ratio, viscosity, and density of the phases (Johnson, 1946). Stokes' Law has often been used to estimate the rate of emulsion destabilization (Petrowski, 1976). It states that $V = 2/9 \left[r^2(s_1-s_2)g/n\right]$, where V = velocity of droplet coalescence, r = radius of dispersed droplets, s_1 = specific gravity of the continuous phase, s_2 = specific gravity of the dispersed phase, g = force of gravity, and n = viscosity.

In the case of meat emulsions, fat is the dispersed phase and water the continuous phase. The emulsifying agent is proteins, particularly the salt soluble ones, which stabilize the dispersion once it has been made (Saffle, 1968). According to Schut (1976), however, meat emulsions involve a multiphasic system where fat is dispersed in a complex matrix of soluble protein, particles of muscle fibers, connective tissue, and salts. A given amount of shear force is necessary to create the dispersion of fat particles by the meat slurry (Saffle, 1968). In subsequent heat processing the protein is coagulated around the fat droplets, creating a stabilized dispersion (Hansen, 1960). In meat systems the use of mechanical energy to

finely divide the fat creates friction which in turn causes a temperature rise (Townsend, 1976). Heating the emulsion causes more droplet collisions and so a more rapid destabilization is seen (Petrowski, 1976). Favorable conditions for meat emulsion production include many other considerations (Schut, 1976), but the physical properties and structure of a raw, finely comminuted sausage batter resemble a true emulsion so sausage processors refer to it as a meat emulsion (Kramlich, 1971).

Classification of sausage products

The word sausage is derived from the Latin term "salsus," meaning salt. Sausages have been prepared by man from the earliest times to the beginning of recorded history as a means of preserving meat (Tauber, 1976). Unlike solid cuts of fresh meats, sausages represent a wide variation in chemical and physical properties of consumer items (Cassens et al., 1977). Today sausages reflect cultural, environmental, and historical influences as well as flavor preferences (Schut, 1978a).

Sausage products are comminuted meat but vary in type by the spices used and the type of processing (Rust, 1977). Classifying sausages by the manner of processing enables characteristics of each class to be recognized easily. Rust (1977) has grouped sausages into the following classes: fresh, uncooked smoked, cooked smoked, cooked, dry, luncheon meats, and cooked hams and canned meats. Sausages may also be classified as ground or emulsified products (Kramlich et al., 1973). Frankfurters or weiners, bologna, liver sausage, and luncheon loaves are generally emulsified meat products.

Production of meat emulsions

Sausage production methods are as varied as the products themselves. Separating the process of sausage manufacture into different categories allows easier explanation, but no one step is more important than another (Kramlich et al., 1973). Until the mid-fifties and early sixties, the ultimate success of each sausage emulsion batch was in the hands of its maker. Technological approaches to solving stability problems became necessary to reduce expensive and time consuming rework necessary to save poor emulsions (Townsend, 1976). The basic process of making meat sausage emulsions involves mincing lean meat, salt, and ice until the mixture is 4 to 8°C. Fatter meat is added along with spices and fine comminution continued until a temperature of 10 to 12°C is reached (Saffle, 1968). Then the sausage emulsion is encased, cooked to an internal temperature of greater than 60°C, usually chilled, removed from the casing, and packaged (Kramlich et al., 1973).

Several types of comminuting equipment may be used in emulsion production. Grinders are utilized to form irregular meat chunks into uniform cylinders of fat and lean by augering the meat through holes in a plate (Kramlich et al., 1973). Size of the meat pieces may be varied with size of the plate perforations (Saffle, 1968). Mixers are used to mix ingredients uniformly while blenders both mix and provide mechanical agitation to extract salt soluble proteins (Rust, 1977). The silent cutter may also be used to mix the meat ingredients but in addition is also used to reduce the meat particle size (Saffle, 1968). In more sophisticated cutters or bowl choppers, the bowl rotation speed which carries the meat past the knives and the knife speed may

be controlled to comminute or mix as desired (Rust, 1977). Emulsion mills vary in performance and configuration, but the basic design has a stationary plate placed next to a rotating plate. The high speed of the rotating plate causes meat to be drawn in and forced by shearing action between the plates (Rust, 1977). Saffle (1968) has further differentiated an emulsitator from a colloid mill because it has a knife which rotates against a perforated plate. All of these mills or emulsifiers act to produce very fine particle sizes by the high speed (2,000 to 5,000 rpm) shearing action (Brennan, 1970).

After action by the previous comminuting equipment, the meat emulsion is pumped, stuffed, or extruded into a casing. Pump extruders are food pumps and are acceptable for use with very finely comminuted products. Piston stuffers exert a force upon the meat mixtures to force them into casings and continuous stuffers use vanes or twin screws to convey the meat into casings. Linkers or chub machines are attached to, or receive encased product from, the stuffing machines and provide size and shape control of the encased raw sausage (Rust, 1977).

Casings are a means of packaging the comminuted meat and holding it together until the consumer receives it (Rust, 1977). Natural casings are animal digestive tracts which are cleaned and sanitized and include stomachs, bladders, intestines, and bungs (Saffle, 1968). Cloth casings are generally limited to coarsely ground sausage products. Cellulose casings are uniform in size, clean, and easy to handle and are often supplied as shirred sticks for stuffing at high volume rates (Kramlich et al., 1973). They are manufactured from cotton and

regenerated into desired sizes (Rust, 1977). These must be peeled from the product before consumption. Regenerated collagen casings are produced by alkaline extraction and acid swelling of collagenous materials and then formed into desired lengths and diameters. They are edible, similar to animal casings, but possess a high degree of uniformity, as do the cellulose casings (Rust, 1977).

After encasement of the emulsified meat mixture, the casings are hung on a bar and placed in a cooking chamber. Smoke may be added to the product and the temperature raised to the desired level. Smokehouses generally provide for control of temperature, humidity, smoke density, and air circulation to regulate product characteristics such as flavor, odor, color, and stability (Saffle, 1968). A common procedure for cooking the emulsion is to start at a temperature of 60°C and raise it 5°C every 15 minutes until 82°C is reached. The relative humidity may vary from 30 percent to 80 percent. After the product reaches an internal temperature of 61 to 63°C, it is showered with hot water to remove any surface fat, then with cold water to reduce product temperature (Saffle, 1968). After being chilled to approximately 4°C, the sausage is peeled or sliced, packaged, assembled, and shipped to the consumer market (Kramlich et al., 1973).

Insights on meat emulsion research

Because the manufacture of a stable meat emulsion is a complicated process, many factors influence the stability and formation of the emulsion, including emulsion temperature, mechanical action, protein amount and type, fat type, particle size, and processing of the

product (Rust, 1977). Excellent reviews on the subjects of meat emulsions (Saffle, 1968), emulsions in comminuted meat systems (Gordon, 1969a and b), processing factors (Sulzbacher and Swift, 1970), meat emulsions (Sulzbacher, 1973), meat sausage rheology (Gorbatov and Gorbatov, 1974), and emulsion technology (Webb, 1974) are available for more detailed information than will be presented here.

Several concepts are important in understanding the previous research published on meat emulsions. Early researchers concentrated on individual components of fat, water, and protein in meat emulsions, while the latest studies have integrated the complex factors which influence successful emulsion production. Studies have centered on fat emulsifying capacity and emulsion stability, but the ability to bind fat does not necessarily mean the fat will remain bound, or stable, during processing. The emulsifying capacity may be defined as the maximum amount of fat or oil with which a given amount of meat or protein will combine to form an emulsion until the emulsion collapses. Emulsion stability refers to the ability of the formed emulsion to remain unchanged until processing is completed (Townsend, 1976). Model systems were developed to determine emulsifying capacity and maintain control over all factors but the variable being tested (Saffle, 1968). Stability tests attempt to simulate the stresses encountered in processing and have included cooking tests, centrifugation, viscosity measurement, differential thermal analysis, nuclear magnetic resonance, electrical resistance, and moisture homogeneity (Townsend, 1976). A subjective phase testing method (Ackerman et al., 1979) and determination of fat cell rupture (Tinbergen and Olsman, 1979)

have also been used to determine emulsion stability. Two major properties influence the stability of a meat emulsion: the water-holding capacity (WHC) of the proteins and fat-holding capacity (FHC) of the protein matrix (Schut, 1976).

Factors influencing water-holding capacity

Hamm (1960) presented an excellent review of meat hydration and the factors which determine water-holding capacity (WHC). Muscle proteins are responsible for the binding of water in meat. There are three basic types of protein in muscle. Myofibrillar proteins constitute 50 percent of the muscle proteins and are mainly comprised of actin and myosin (Hamm, 1960). These proteins are soluble in concentrated salt solutions (ionic strength 0.5 to 0.6) and function as myofibril contractile mechanisms in the muscle (Schut, 1976). Stromal proteins comprise 15 to 17 percent of the muscle and are considered to be binding proteins which hold muscle bundles together and link muscle to bone (Forrest et al., 1975). These stromal, or connective tissue proteins, have unique characteristics. Collagen undergoes thermal shrinkage and then conversion to gelatin upon heating because it is composed of 33 percent glycine and 10 percent each of hydroxyproline, alanine, and proline, which are highly polar amino acids. It is also characterized by intra- and intermolecular crosslinks which increase with animal age (Kramlich et al., 1973). Elastin has very elastic properties and is extremely unreactive while reticulin is similar chemically to collagen (Kramlich et al., 1973). Sarcoplasmic proteins are often called water-soluble proteins since they are soluble in low ionic strength

solutions (< 0.1). They account for approximately 30 percent of the muscle proteins and serve as enzymes and heme pigments in the muscle cells (Forrest et al., 1975).

There are two main types of water which may be found in muscle tissues. Tightly bound water, or hydration water, is bound by the hydrophilic side chains of the protein (Schut, 1976). Free water is immobilized in a network of membranes and in the filaments of the structural proteins (Hamm, 1960). Water-holding capacity (WHC) then refers to the ability of meat to hold its own or added water during the application of force (Hamm, 1960). Most methods of measuring water-holding capacity of meat have used physical means to apply pressure on meat. Pressing meat between two plates has been used in studies by Grau and Hamm (1953), Wierbicki et al. (1957), Briskey et al. (1960), and Hamm and Deatherage (1960). Other methods have included sedimentation, centrifugation, and filtration to measure WHC (Hamm, 1960).

Meat is a complex molecular system, and thus many factors influence WHC. Meat of young animals is considered to have a higher WHC than meat from older animals (Schut, 1976). Pork has a higher WHC than beef, but there is a large difference between muscles at different locations in each animal's body (Hamm, 1960). Other factors influence WHC to greater extents than the above factors, or the breed, sex, grade, or nutrition of the animal. Changes in protein charges, or pH changes, binding of divalent cations, neutral salt addition, salts of weak acids, and sarcoplasmic salts determine a majority of the water retention in meat (Schut, 1976).

The pH has a pronounced effect on WHC of muscle. On either side of the isoelectric point of pH 5.0, where protein side chain net charge is zero, the WHC is increased (Hamm, 1960). This sharp increase is explained by cleavage of salt bridges between peptide chains and by an increase of net charge of the protein (Schut, 1976). At a pH less than 5.0, addition of protons leads to a majority of undissociated carboxyl groups, resulting in a positive net charge. The positively charged side groups repel one another, and water is able to enter this larger space between chains. A similar effect is seen when pH is greater than 5.0. The amino groups lose their extra protons and become uncharged. The negatively charged side groups of the carboxyl side groups repel one another and again water is able to enter the increased space between side chains (Lehninger, 1975). This influence of pH is known as the net charge effect, but this accounts for only about one-third of the water loss as pH decreases postmortem (Forrest et al., 1975).

A steric effect on WHC is also seen in muscle (Forrest et al., 1975). Bivalent cations such as Ca^{++} or Mg^{++} are naturally present in muscle to function in the contraction mechanism. With loss of ATP, as occurs during slaughter and postmortem storage, these bivalent cations are released into the myofibrillar spaces. The bivalent cations cause actin and myosin to bind together (muscle contraction), resulting in less myofibrillar WHC. In addition, the bivalent cations may bind to negatively charged carboxyl side chains of the protein. A bond may be made between two such bivalent cations, creating a bridge between the side groups. This tends to reduce intra- and intermolecular spaces

and thus decreases the space for free water to enter the myofibrils (Schut, 1976). Monovalent cations exert an affinity for myosin and actomyosin, but not for actin. They cause an influence upon WHC, due to electrostatic attraction to protein, but the effect is much weaker than from bivalent cations, as shown by Swift and Ellis (1956).

Addition of neutral salts, such as sodium chloride, causes swelling of the myofibrils and an increase in WHC (Schut, 1976). Hamm (1960) stated that in the basic range of pH, neutral salts hydrate muscle, causing increased WHC, while in the acidic pH range, neutral salts dehydrate the tissue and cause water binding to decrease. Sherman (1961) showed that anions were absorbed preferentially over cations into fresh pork, causing a greater WHC since meat pH is on the alkaline side of the isoelectric point of muscle. Sherman (1962) demonstrated that water retention in fresh pork was related linearly to the concentration of ions absorbed. This supported his earlier work (Sherman, 1961) where he found a greater absorption of ions with greater ionic strengths of the solutions.

The addition of salts of weak acids, such as citrates and polyphosphates is practiced in many countries (Schut, 1976). Sherman (1961) reported that polyphosphates increased WHC, but this was not attributed to their ability to complex calcium and magnesium ions. Swift and Ellis (1956) had earlier shown the effect of pyrophosphates was related to pH and ionic strength levels. Sherman (1962) stated that there was an effect of phosphate ion absorption at higher pH, as the difference between anion and cation absorption decreased. Schut (1976) concluded that four phenomena must be considered in the action of

salts of weak acids on WHC of meat. The bivalent cations which strongly bind to proteins are partially diminished. Magnesium diphosphate causes a decrease in binding of actin and myosin. In addition, salts of weak acids exert an ionic strength and have an effect on pH. All of these factors cause a swelling of the meat tissue and an increase in WHC. Salts of the sarcoplasm cause an increase in WHC similar to the addition of other salts. The anion effect on WHC is caused by the chloride, lactate, phosphate, and sulfate groups present in the sarcoplasmic protein fraction (Schut, 1976).

Water and fat binding in the protein matrix

Since meat emulsions are considered the oil-in-water type, the protein is important as an emulsifying agent (Schut, 1976), but other factors also influence the formation and stability of meat sausage batters. Hansen (1960) reported that water-soluble proteins (sarcoplasmic) would not emulsify pork fat while salt-soluble proteins (myofibrillar) did cause emulsion formation. Swift et al. (1961) prepared emulsions using both water-soluble and salt-soluble proteins but determined salt-soluble proteins emulsified much more fat per mg protein than the water-soluble proteins. Fat was emulsified with water-soluble proteins at pH 5.2 by Swift and Sulzbacher (1963), but the emulsifying capacity was lowered using alkaline or acidic solutions. Trautman (1964), however, failed to emulsify fat with water-soluble proteins.

Swift et al. (1961) had reported the efficiency of salt-soluble proteins varied inversely and curvilinearly with concentration as the more highly concentrated protein solutions emulsified less fat than

lower concentrations of protein solutions. Hegarty et al. (1963) also found the emulsifying capacity varied inversely in a curvilinear relationship with protein concentration. Myofibrillar proteins were purified and the order of maximum emulsifying capacity was determined to be actin in the absence of salt, myosin, actomyosin, sarcoplasmic proteins, and actin in 0.3M salt in the previous study (Hegarty et al., 1963). Tsai et al. (1972) also tested purified proteins and agreed with Hegarty et al. (1963) that there was an inverse curvilinear relationship between protein concentration and emulsifying capacity. Heating of emulsion cores produced with the purified proteins showed myosin produced the most stable, uniform emulsions, while actin lost water during the heat treatment. Sarcoplasmic proteins were found least desirable for emulsion formation in that study (Tsai et al., 1972).

Several studies have compared emulsifying properties of various meat sources. Saffle and Galbreath (1964) evaluated many meat sources for percentage of salt-soluble proteins. Meats high in elastin and collagen content contained less salt-soluble proteins than meat sources lower in connective tissue. Carpenter and Saffle (1964) reported the emulsifying capacity (ml oil/100 mg soluble protein) was lower in meat high in connective tissue than in meat with lesser amounts of connective tissue. Miller et al. (1968) analyzed various sausage materials for ability to retain water. The ability to bind water decreased as fat content of the meat increased. The same amount of water binding was found for meat with high as for low connective tissue contents, since gelatin is capable of holding large amounts of water. Wiley et al. (1979) chemically analyzed the amounts of

collagen and soluble collagen in different sausage meats. Bind values were found to be higher for meats higher in soluble collagen content. Little difference was reported among the sausage meats for amounts of water and fat lost even though total collagen, soluble collagen, and insoluble collagen values varied widely among the meats sampled.

Borton et al. (1968), in testing meat trimmings, reported a higher emulsifying capacity per unit weight of sample with lean meat sources, but fat meat sources were more efficient emulsifiers of fat, with higher emulsion capacities per unit of protein than lean meat sources. Acton and Saffle (1972b) found the emulsifying capacity decreased with increased protein concentration (mg/ml), but total ml of oil emulsified increased with increased protein concentration. Gillett et al. (1977) determined that meat sources varied greatly in amount of protein extracted and in emulsifying capacity. They explained the discrepancy in previous research between amount of oil emulsified per amount of extract and the amount of oil emulsified per amount of protein by graphing both values for each meat source. The amount of soluble protein varied with the meat source, causing the differently shaped curves depending on whether the amount of oil emulsified was expressed per weight of protein (positive linear curve) or per volume of extract (negative curvilinear relationship) in this study (Gillett et al., 1977).

Swift and Sulzbacher (1963) found that increased salt concentrations increased the emulsifying capacity of the salt-soluble proteins. Fat was emulsified with a salt concentration range of 0.3M to 1.2M by the salt-soluble proteins. Trautman (1964) found maximum protein

extraction at 10 percent salt levels. He also found that the amount of protein extracted increased with the time allowed for extraction. This has been the basis for preblended sausages where lean meat is ground and mixed with salt and then stored for later use in emulsions (Shannon, 1978). Borton et al. (1968) reported that prechopping and salting of meat 18 hours prior to emulsification enhanced the emulsifying capacity per unit of protein. Acton and Saffle (1969) found that preblended meat had more soluble protein and emulsified more fat than meat which was not presalted. Waldman et al. (1974) reported that preblended meat caused a slight increase in pH of the raw materials. Terrell (1974) stated that presalting of meat allowed longer extraction times and production of firmer textures. Johnson et al. (1977) showed that preblended meat had a greater soluble phase and higher total soluble protein levels than meat in which salt was added during emulsification. They also reported that preblended meat had a much lower soluble phase but higher total soluble protein compared to unblended meat with no salt added. Gillett et al. (1977) reported that maximum protein extraction and emulsifying capacity occurred at 9 percent salt levels.

Saffle and Galbreath (1964) established a relationship between the amount of salt-soluble protein extracted and pH. At higher pH levels found in prerigor meat, 50 percent more salt-soluble protein was extracted than from postrigor meat which had lower pH values. Trautman (1964) found that prerigor meat greatly superior to postrigor meat in the ability to emulsify fat, since three times more soluble protein was extracted from prerigor than postrigor meat (Bard, 1965). Trautman (1964) determined that prerigor meat samples contained

42 percent of the extracted protein as salt-soluble proteins, while postrigor samples had 39 percent salt-soluble proteins in the extracted protein. Acton and Saffle (1969, 1972b) agreed with previous researchers that prerigor meat had a greater emulsifying capacity and a larger percentage of extracted salt-soluble protein than postrigor meat. Stilwell et al. (1978) processed frankfurters containing pre- and postrigor pork. A greater release of water and lower water-holding capacity was found in prerigor pork, however, differences in emulsion properties between frankfurters made with accelerated processed (prerigor) pork and conventionally processed (postrigor) pork were not found in analyses of the final product. No significant difference in emulsification capacity was obtained between pre- and postrigor pork in the previous study (Stilwell et al., 1978).

Temperature also influences binding properties of meat proteins. Swift et al. (1961) used liquified fat in a model system and found maximum emulsification was obtained at the lowest temperature (18°C) of the water and salt-soluble protein suspensions. Helmer and Saffle (1963) studied the effect of chopping temperature on stability of emulsions. Emulsions chopped to 15.5°C were stable but higher temperatures caused unstable emulsions to be produced. Trautman (1964) reported maximum extraction of salt-soluble proteins at -5°C, and less extraction at higher temperatures. Webb et al. (1975) found decreased cook stability when the initial temperature of chopping the lean beef, salt, ice, and some of the pork fat exceeded 5°C. Cook stability remained constant when the final chopping temperature was 25°C or below, but decreased greatly when a final chopping temperature

of 27.5°C was reached. Brown and Toledo (1975), using nuclear magnetic resonance techniques, concluded that the final temperature range of the meat batter was 15 to 22°C where maximum binding occurred. Johnson et al. (1977) reported significant ($p < .01$) correlations between the emulsion temperature and soluble protein concentration, total soluble protein, and cooked emulsion stability. Maximum protein extraction and greater oil emulsification was seen at 7.2°C by Gillett et al. (1977). However, greater emulsifying capacity per weight of protein was observed at 1.7°C in this study.

Webb et al. (1975) stressed that temperature control was important in fat emulsification and stabilization. They reported requirements for a low extraction temperature (5°C), high temperature for fat addition (76.7°C), and a low final chopping temperature of less than 25°C. Swift et al. (1968) had earlier characterized the effect of fat melting temperature on emulsion stability. All emulsions containing 12 percent fat levels were stable, while emulsions which contained 22 percent fat were stable only if a high-melting fat was utilized. Townsend et al. (1968) determined there were two primary melting ranges of fat. Differential thermal analysis disclosed that beef fat melted at ranges of 3 to 14°C and 18 to 30°C, while pork fat melted at ranges of 8 to 14°C and 18 to 30°C. Emulsions comminuted to greater than 18.5°C, which coincided with the higher melting range, were unstable.

Christian and Saffle (1967) earlier had found more of the shorter chain fatty acids were emulsified than longer chain fatty acids when purified fatty acids were tested. Fatty acids with one double bond

were emulsified more than fatty acids with two double bonds, while saturated fatty acids were emulsified the least when chain length of the fatty acid was constant. They also reported that more animal fat could be emulsified per amount of salt-soluble protein than the purified fatty acids. Range of emulsification of various fats from beef, pork, mutton, and chicken sources was relatively narrow in that study (Christian and Saffle, 1967). Ackerman et al. (1971) concluded that pork fat resulted in greater emulsion stability because it was more widely dispersed than beef fat. Schut (1976) stated the interfacial tension was correlated with melting temperatures of the fats, and production of stable emulsions was more favorable with pork fat than beef fat when the temperature was less than $50^{o}C$ for the fat.

Hegarty et al. (1963) had proposed the amount of protein utilized in the formation of an interface was related to emulsion stability. Ivey et al. (1970) measured emulsifying characteristics and interfacial film thickness. The emulsifying capacity had no effect on the interfacial film thickness at the point of emulsion collapse. When emulsion stability was determined, more stable emulsions were produced with thicker interfacial films surrounding the fat droplets. As fat droplet size decreased, more protein was required at the interface to maintain stability. They concluded that the amount of water in the emulsion influenced the amount of oil which could be emulsified and still result in a stable emulsion. Morrison et al. (1971) found that proportions of lean and fat could vary over a wide range without affecting emulsion stability, but the emulsion instability was highly dependent upon the level of added water. Brown and Toledo (1975)

showed the amount of water bound to the interface of the fat and protein film increased with more chopping time to a maximum value, and then decreased to cause unstable meat batters. Acton and Saffle (1972a) reported that the ability to form interfacial films would contribute to emulsion stability.

Hansen (1960) prepared stained sections of meat emulsions at progressive intervals during chopping. With increased chopping time, the fat cells were broken within a few minutes but muscle fibers were disintegrated more slowly. Fat separation occurred at chopping times of one and five minutes, but no separation was observed when emulsions were chopped eight, 10, or 12 minutes. Chopping emulsions to final temperatures of 23.3 and 26.7°C resulted in breakage of the protein matrix, but no fat separation occurred. Complete breaking of the protein matrix was observed when chopping temperature reached 27.2°C. A concentration of protein formed an intact skin around the fat globules when salt-soluble proteins were used, but the water-soluble preparations resulted in holes in the stained protein film surrounding the fat.

Helmer and Saffle (1963) made photomicrographs of emulsions chopped to different temperatures. At a chopping temperature of 15.5°C, the fat globules were small but enlarged as temperature increased. At 26.7 and 32.2°C, the fat globules combined and formed large fat lakes. Emulsion breakdown occurred in all emulsions chopped to 21.1°C or greater temperatures. Carpenter and Saffle (1964) produced photomicrographs which showed the protein layer around each globule became thinner as more oil was added until the oil globules

coalesced and the emulsion collapsed. Borchert et al. (1967) examined meat emulsions under an electron microscope and observed that fat globules as small as 0.1 micron in diameter had distinct protein membranes. After heating, the fibrous protein of the continuous phase was disrupted and coagulated into dense, irregular zones. Ackerman et al. (1971) determined that fat particles 200 microns or greater in diameter tended to separate from frankfurters containing beef fat. Increased comminution to 23.9°C was necessary to produce the finely dispersed fat particles to prevent fat separation. Overchopping was seen in the photomicrographs when chopping continued to 27.8°C.

Cassens et al. (1977) used oil red O to stain fat and picro-ponceau to identify connective tissue in examining histological samples of sausages. Differences between products were found for degree of fat dispersion and protein structure in emulsions. Theno and Schmidt (1978) also used different brands of frankfurters for study under light and scanning electron microscopes. Structures ranged from coarse protein matrices with large fat particles to uniformly dispersed, small fat droplets in a fine matrix structure in the frankfurter emulsions. Ray and others (1979) developed a technique for positive identification of fat and protein components in scanning electron micrographs using liver sausage and frankfurter samples. Serial sections were sliced and viewed under light and scanning electron microscopes. Selective fixing of the serial sections for fat with osmium tetroxide, removal of fat with Zenker's solution, and fat and protein components differentiated by oil red O and Delafield's hematoxylin, respectively, allowed comparison of light and scanning electron micrographs of the

same magnification. In this study, fat particles were globular and surrounded by an absorbed layer of protein particles. Tinbergen and Olsman (1979) reported that the level of extractable fat was significantly ($p < .01$) correlated with percentage of fat separation after heating to 80°C over a wide range of chopping temperatures. They stated that fat which separated from the emulsions was present as free fat from ruptured tissues and microscopic examinations revealed the remaining fat was enclosed in intact cell structures which resisted extraction treatment.

In the study by Ray et al. (1979), air pockets within the protein structure were observed. Schmidt (1979) reported that vacuum mixing was more effective at extracting myofibrillar proteins than mixing which allowed air incorporation. It has been suggested by Wirth (1978) that vacuum mixing and chopping prevents air incorporation, allowing protein to encapsulate fat rather than air bubbles. Starr (1979) thought that producing emulsions under vacuum conditions would allow lower binding proteins to replace more expensive, higher binding proteins in formulations.

It is evident from the research reported that many factors influence formation and stability of meat emulsion structures. Schut (1976) postulated that disruption of the protein matrix occurs at a temperature at which the fat particles are immobilized by the partially solidified matrix. Water-holding capacity of the meat (Schut, 1976), the insoluble component of the continuous phase (Johnson et al., 1977), integrity of fat cells rather than availability of released fat for emulsification (Tinbergen and Olsman, 1979), and improving the density of structure

by air removal (Wirth, 1978) are only a few of the considerations influencing emulsion stability which deserve further study.

PART I.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF FRANKFURTERS PREPARED WITH MECHANICALLY PROCESSED PORK PRODUCT

INTRODUCTION

More than 1.9 billion pounds of frankfurters are produced each year in the U.S. (National Hot Dog and Sausage Council, 1979). As the demand for meat trimmings increases, alternative sources of materials for processed meat become more important (Brown, 1975). The possible use of mechanically processed (red meat species) product has been reported in cooked salami (Joseph et al., 1978), dry fermented salami (Berry et al., 1979), ground beef (Cross et al., 1977; Seideman et al., 1977; Emswiler, et al., 1978; and Cross et al., 1978a), and bologna (Field et al., 1974a; Chant et al., 1977; and Misock et al., 1979). These studies have indicated that low levels of usage are acceptable in comminuted products.

The USDA has published a final ruling on mechanically processed (species) product, setting production requirements, labeling rules, compositional guidelines, and permitted uses, including usage in frankfurters (Federal Register, 1978). Where mechanically processed pork product has been used in frankfurter production (Meiburg et al., 1976; and Marshall et al., 1977), research has centered on storage stability, consumer acceptability, flavor, and subjective processing traits. The present study determined the processing characteristics, emulsion stability, and chemical composition of frankfurters which contained progressive levels of mechanically processed pork product (MPPP).

EXPERIMENTAL

Frankfurters were manufactured using frozen beef trim, pork backfat, and mechanically processed pork product (MPPP). MPPP was produced by prebreaking young, commercially-trimmed pork backbones in a Weiler grinder (2.54 cm plate), then passing the ground bone through a Kartridg-Pak Meat Removal System, a hydraulic press deboner. The Meat Removal System was operated at a pressure of 27600 kilopascals, dwell time of five seconds for pressure application, and 0.23 mm opening between the concentric separation rings. After the deboning process, the MPPP was quickly frozen in a CO_2 cryogenic tunnel and stored at -15°C for two weeks. In formulating the frankfurters (Table 1), thawed (0°C) beef trim was ground through a 0.95 cm plate, weighed and then analyzed for fat with an Anyl-Ray (Kartridg-Pak, Inc.) machine. The proper amount of beef trim determined to contribute 21 percent fat to the final formulation, 3 percent salt, and 10 percent added ice were chopped to 8°C in a 45 cm diameter Hobart laboratory silent cutter. Thawed MPPP (1°C) was added at 0, 10, 20, 30, 40, or 50 percent levels, and pork backfat was used to adjust the 2.5 kg batches to a constant formulation of 25 percent fat. Chopping was continued to a temperature of 13.5°C. After hand stuffing and linking into 26 mm cellulose casings, the raw meat emulsions were weighed and then processed in a conventional smokehouse to 70°C internal temperature according to the following schedule: 15 minutes at 40 percent R.H. and 54°C, 30 minutes at 63 percent R.H. and 70°C, 10 minutes at 78 percent R.H. and 80°C, and 5 minutes at 80°C and 100 percent R.H. followed by a 3 minute

Table 1. Formulations of frankfurters

Ingredient	Level of MPPP (%)					
	0	10	20	30	40	50
Beef trim (kg)	2.28	2.04	1.81	1.58	1.34	1.11
Pork backfat (kg)	.22	.21	.19	.17	.16	.14
MPPP[a] (kg)	0	.25	.50	.75	1.00	1.25
Other ingredients[b] (kg)	.46	.46	.46	.46	.46	.46

[a]MPPP composition was 56.7% moisture, 26.3% fat, 14.1% protein, 3% ash, .56% calcium, and 3% crude bone.

[b]Ice 375 gm, salt 75 gm, Heller Premier Weiner Seasoning 12.5 gm, sodium erythorbate .6834 gm, and sodium nitrite .1984 for each kg batch.

cold shower. Frankfurters were chilled to 4°C, weighed, and peeled before analysis of the finished product.

Smokehouse yields were calculated by weighing the stuffed casings before smokehouse processing and after chilling. Moisture, crude fat, Kjeldahl protein, and ash were determined on raw emulsions and finished frankfurters by AOAC procedures (AOAC, 1975). Crude bone content was measured by the papain digestion and acetone:carbon tetrachloride procedure of Hill and Hites (1968). Water-holding capacity determination was made by modifying the procedure of Wierbicki and Deatherage (1958) as follows: samples (0.3 g) of raw emulsions and frankfurters were placed on dried, #1 Whatman filter discs and pressed for three minutes in a Carver press at 20690 kilopascals. Meat and juice areas were measured using both a plastic grid calibrated for 20 dots/6.45 cm^2 and a compensating polar planimeter. Water-holding capacity was

expressed as the ratio of juice area to meat area. Expressible juice was calculated by the formula reported by Briskey et al. (1960). Values for the mg of water/square cm of juice area, 5.72 for raw emulsions and 5.55 for frankfurters, used in the formula were determined by the method of Connell (1955). A modified Rongey (1965) stability test was employed to estimate the amounts of fat and water lost during processing. Raw emulsion samples were collected immediately after chopping and placed into weighed Wierbicki tubes. After heating for 30 minutes at 70°C in an open water bath, tubes were cooled 10 minutes and centrifuged at 250 x G for 20 minutes. Volumes of fat and water lost were expressed as a percentage of sample weight. Warner-Bratzler shear force values were obtained on chilled frankfurters after measuring the diameter with a vernier caliper.

Statistical analysis was performed using the SAS analysis of variance procedure (Barr et al., 1976), Duncan's multiple range tests (Duncan, 1955), and t-tests (Steel and Torrie, 1960). Three replications of each of the six formulations (0, 10, 20, 30, 40, and 50 percent MPPP) were processed in a completely randomized fashion. The analysis of variance tables are shown in appendix tables A.1, A.2, and A.3.

RESULTS AND DISCUSSION

The proximate analyses for raw emulsions are listed in Table 2. Fat and protein composition was held fairly constant for all raw formulations by adjusting the pork backfat ingredient levels. Moisture level, ash content, and bone content increased as level of MPPP used in the formulations increased. The increase in ash and bone contents would be expected, as minerals and bone particles are forced through the deboner along with the muscle tissue (Field et al., 1975). The finished frankfurter composition (Table 3) showed no difference in protein content among treatments, but frankfurters with 40 and 50 percent levels of MPPP contained less moisture and more fat than in frankfurters with the other levels of MPPP. Ash and bone content increased as level of MPPP increased in the frankfurters since MPPP contains a greater ash and bone content than muscle tissue. As seen in Tables 2 and 3, moisture:protein ratios of 40 and 50 percent MPPP formulations were higher than other treatments in raw emulsions, but the ratios were lower in the finished frankfurters.

Raw emulsions which contained 20 percent MPPP resulted in the greatest smokehouse yield of frankfurters (Figure 1). The vertical lines at each level of MPPP in Figure 1 represent the wide ranges of yields over the three replications of each MPPP level in the formulations. The yield of frankfurters with 0 or 20 percent MPPP was significantly ($p < .05$) higher than yields of frankfurters with 10, 40, or 50 percent levels of MPPP (Table 4). Smokehouse yield was significantly correlated ($p < .05$) with the amount of fat present in

Table 2. Proximate analysis values for raw emulsions

Component[1] (%)	Level of MPPP 0	10	20	30	40	50	SEM[2]
Moisture	60.51^{a}	60.65^{a}	60.91^{ab}	61.21^{ab}	61.71^{b}	61.85^{b}	.08
Fat	21.99^{a}	21.76^{a}	21.88^{a}	21.96^{a}	21.76^{a}	20.97^{b}	.17
Protein	14.13^{a}	13.19^{bc}	13.32^{bc}	13.53^{b}	13.01^{c}	13.14^{c}	.12
Ash	3.08^{a}	3.12^{a}	3.27^{bc}	3.21^{ab}	3.37^{cd}	3.42^{d}	.02
Bone content	.04^{a}	.11^{ab}	.18^{bc}	.25^{d}	.22^{cd}	.35^{e}	.01
Moisture:protein ratio	4.28^{a}	4.60^{bc}	4.57^{bc}	4.53^{b}	4.77^{d}	4.71^{cd}	.04

[1]Means for each component with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

Table 3. Composition of finished frankfurters

Component[1] (%)	Level of MPPP						
	0	10	20	30	40	50	SEM[2]
Moisture	54.58^{a}	54.69^{a}	54.31^{a}	54.91^{a}	52.98^{b}	53.18^{b}	.24
Fat	24.89^{ab}	24.91^{ab}	24.27^{a}	24.81^{ab}	26.60^{c}	25.83^{bc}	.40
Protein	16.44^{a}	16.38^{a}	16.45^{a}	16.35^{a}	16.38^{a}	16.25^{a}	.11
Ash	3.49^{a}	3.58^{a}	3.74^{b}	3.81^{b}	3.99^{c}	3.84^{b}	.05
Bone content	.09^{a}	.08^{a}	.18^{ab}	.22^{b}	.41^{c}	.46^{c}	.03
Moisture:protein ratio	3.32^{ab}	3.34^{ab}	3.30^{abc}	3.37^{a}	3.23^{c}	3.28^{bc}	.03

[1]Means for each component with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

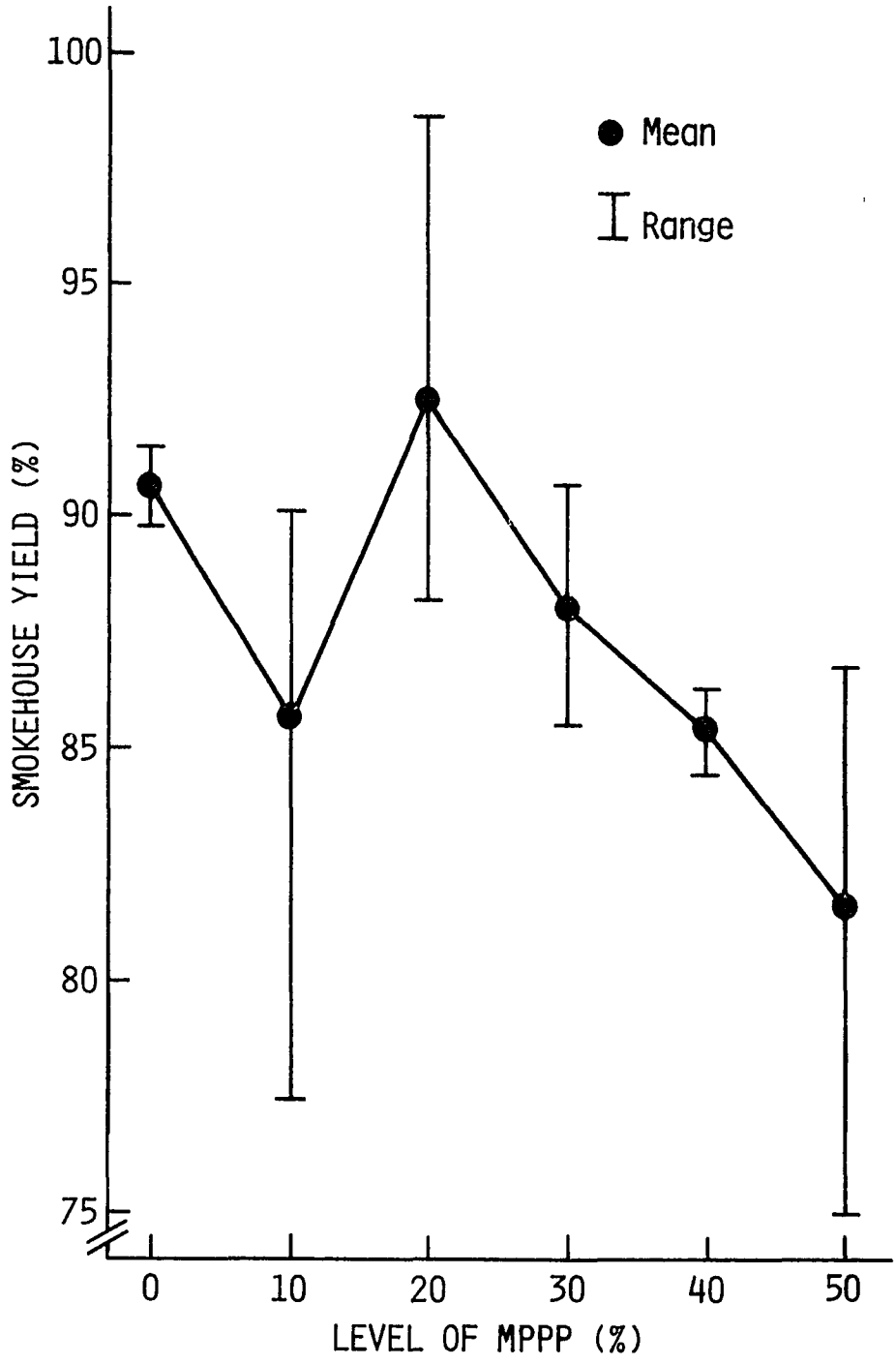


Figure 1. Smokehouse yield means and ranges for increased levels of MPPP

Table 4. Mean values[1] and standard errors of means[2] for physical characteristics of frankfurters

Characteristic	Level of MPPP						
	0	10	20	30	40	50	SEM[b]
Smokehouse yield (%)	90.69^{ab}	85.73^{c}	92.45^{a}	88.00^{bc}	85.47^{c}	81.73^{d}	1.22
Emulsion stability							
Water released (%)	5.14^{a}	5.11^{a}	4.61^{a}	5.47^{a}	7.96^{b}	9.98^{b}	.84
Fat released (%)	1.02^{ab}	1.12^{ab}	.73^{a}	1.45^{b}	2.12^{c}	3.03^{d}	.21
Total released (%)	6.15^{a}	6.23^{a}	5.34^{a}	6.92^{a}	10.08^{b}	13.01^{c}	.84
Warner-Bratzler shear force (kg)	2.79^{a}	2.75^{a}	2.16^{b}	1.44^{c}	1.08^{d}	0.99^{d}	.04
Frankfurter diameter (mm)	22.80^{a}	22.78^{a}	22.42^{a}	21.10^{b}	21.45^{b}	20.92^{b}	.22
W-B shear/diameter (kg/mm)	.122^{a}	.121^{a}	.096^{b}	.067^{c}	.050^{d}	.047^{d}	.002

[1]Means for the same characteristic with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

finished frankfurters (Table 5). Simple correlation coefficients between smokehouse yield and water and fat loss in the emulsion stability test were -.34 and -.53, respectively, indicating the emulsion stability test explains some but not all of the variation in yield. No large differences in water, fat, or total fluid loss were observed among levels of MPPP to 30 percent (Table 4, Figure 2), but a significantly greater ($p < .05$) increase in weight loss occurred for the 40 and 50 percent levels of MPPP. The amount of water lost was highly correlated ($r = .70$) with the amount of fat lost in the stability test. Morrison et al. (1971) and Brown and Toledo (1975) found that the amount of water bound to the interface of the fat and protein film influenced emulsion stability. In the present study, raw emulsions with lower moisture:protein ratios produced more stable frankfurters than raw formulations (40 and 50 percent MPPP) with higher moisture: protein ratios, but low correlation coefficients of -.20, .20, and .28 were obtained between raw emulsion moisture:protein ratios and yield, water lost, and fat lost, respectively (Table 5). Marshall et al. (1977) previously reported that frankfurters containing MPPP had more "fatting-out" problems than control frankfurters and use of 25 and 40 percent MPPP levels resulted in greater smokehouse shrinkage percentages than control or 10 percent level MPPP frankfurters.

Water-holding capacity (WHC) and expressible juice percentage for raw emulsions and frankfurters are shown in Figure 3. Values for WHC closer to one indicate a greater ability to retain or hold water. Lower values for expressible juice also indicate increased water retention by the samples. At each level of MPPP, raw emulsions held

Table 5. Simple correlation coefficients for processing characteristics

	1	2	3	4	5	6	7	8
1 Smokehouse yield	1.00	-.34*	-.53**	.35*	.28	.36*	-.20	-.40*
2 Emulsion stability water lost		1.00	.70**	-.28	-.50**	-.60**	.20	.42*
3 Emulsion stability fat lost			1.00	-.48**	-.59**	-.68**	.28	.42*
4 Raw emulsion water-holding capacity (grid)				1.00	.55**	.57**	-.28	-.43**
5 Frankfurter diameter					1.00	.77**	-.26	-.48**
6 Frankfurter Warner-Bratzler shear force						1.00	-.42**	-.47**
7 Raw emulsion moisture: protein ratio							1.00	.43**
8 Frankfurter fat composition								1.00

*$p < .05$.

**$p < .01$.

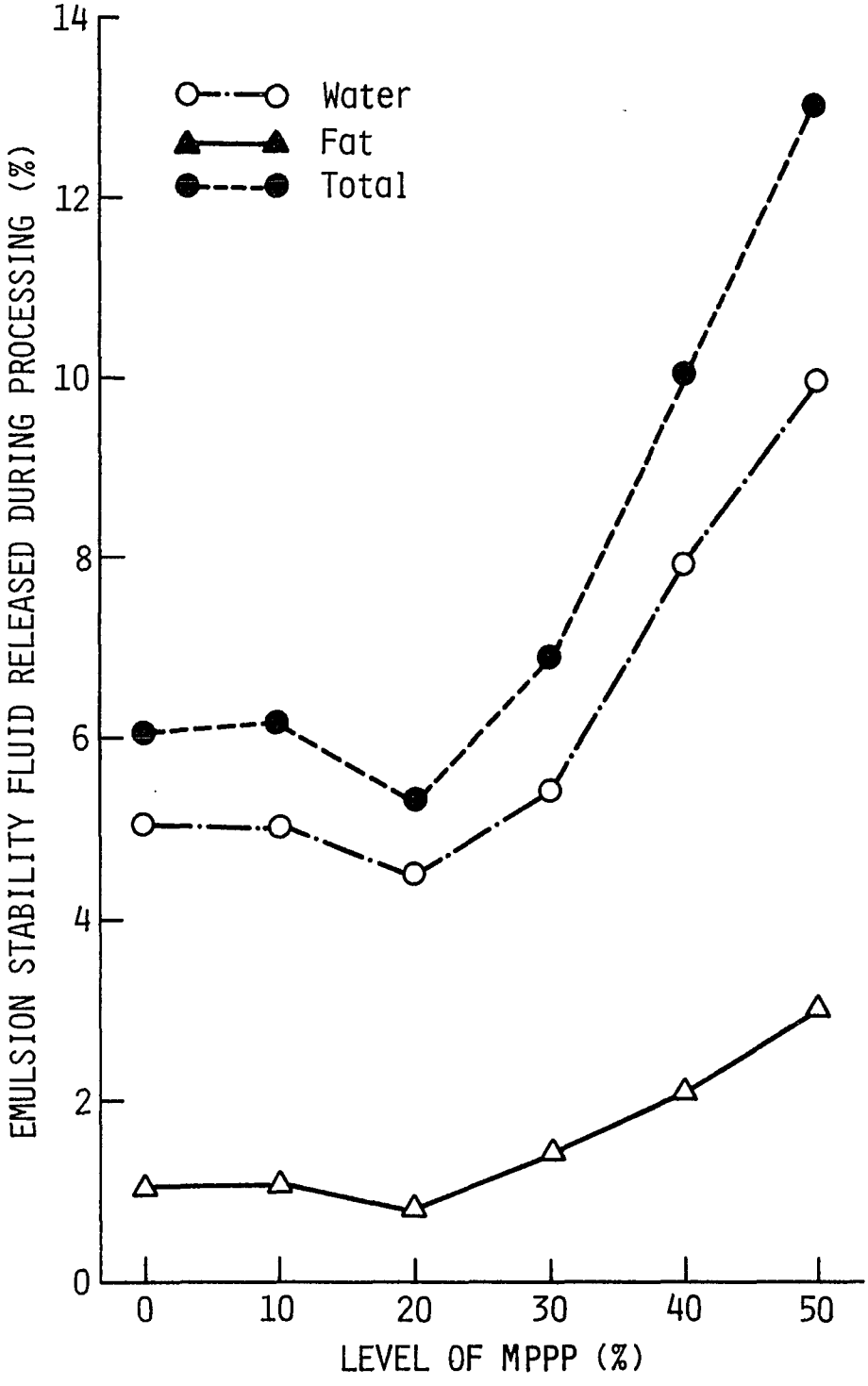


Figure 2. Emulsion stability expressed as percent of water, fat, and total fluid released with increased levels of MPPP

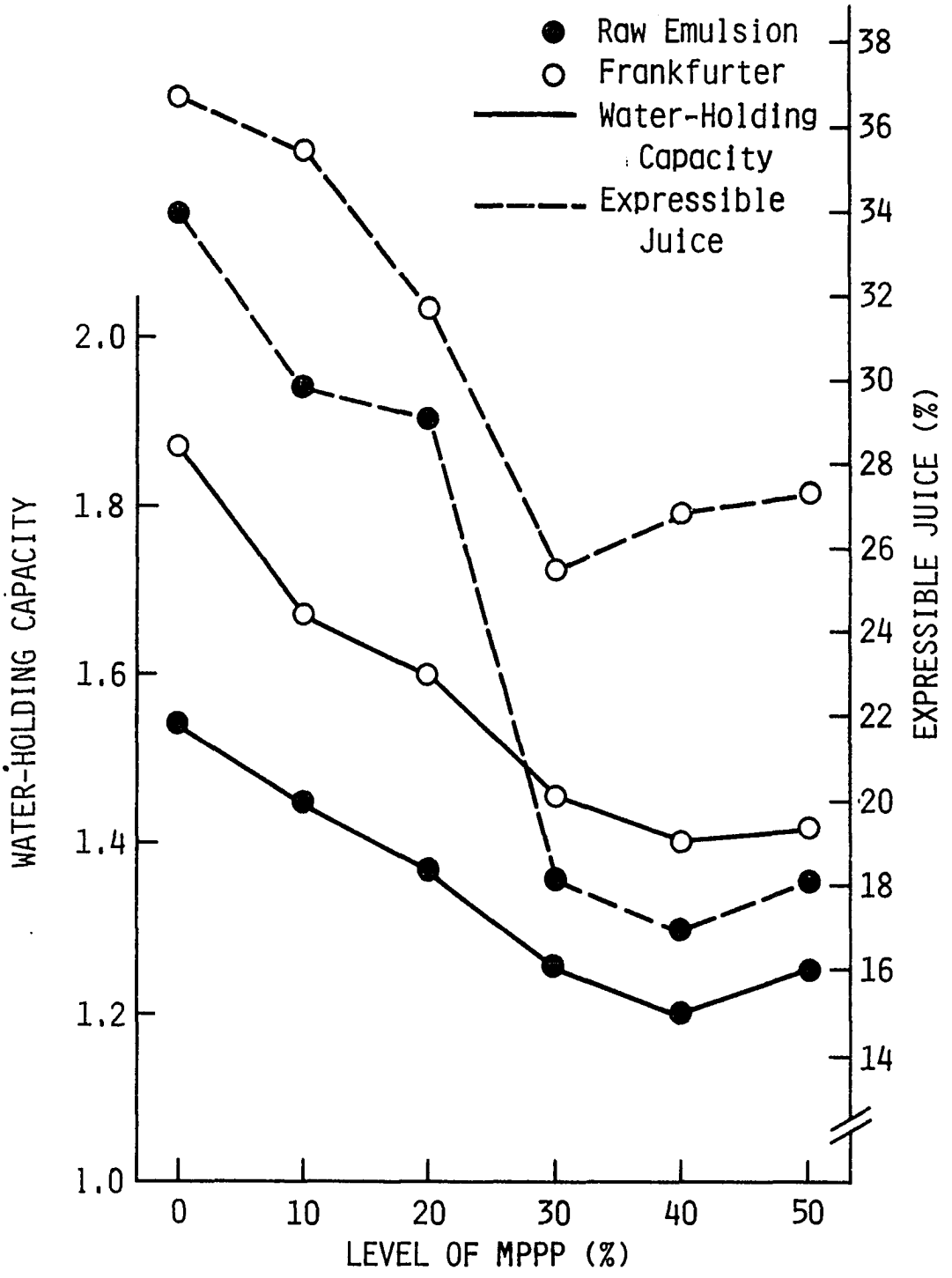


Figure 3. Water-holding capacity and percent expressible juice by grid area measurement for raw emulsions and finished frankfurters

water more tightly than frankfurters of the same formulation. Hamm and Deatherage (1960) reported less water bound with meat heated to temperatures greater than 40°C than meat which remained at a lower temperature. In the present study, internal temperature of the frankfurters reached 70°C during the smokehouse heating. The WHC increased as the level of MPPP increased for both raw emulsions and frankfurters. The ability of the 0, 10, and 20 percent MPPP formulations to hold water during the application of pressure was significantly less ($p < .05$) than for the 30, 40, and 50 percent formulations in both raw emulsions and frankfurters (Table 6). Expressible juice measurement also showed the decreased ability of the control, 10 percent, and 20 percent MPPP formulations to hold water (Figure 3). The great difference in WHC or juice retained may be explained by comparing the MPPP structure to meat which has been ground. Hamm (1959) stated that grinding of meat increases hydration because more polar groups of proteins become available for the binding of water dipole molecules. Most MPPP is produced in the form of a paste (Froning, 1970) since the seiving device must have an opening less than 0.5 mm (Federal Register, 1978). The increased size reduction of MPPP muscle tissue which occurs during deboning compared to grinding of the muscle tissue may cause more protein side groups to be available for water binding. Formulations with increased amounts of MPPP would then exhibit greater WHC, as was observed in this study. The raw emulsion WHC was correlated with smokehouse yield ($r = .35$) and the amount of fat lost in the stability test ($r = -.48$), but WHC was not highly correlated with the

Table 6. Mean values[1] and standard errors of means[2] for planimeter and grid area measurements of water-holding capacity and expressible juice

	Level of MPPP					
	0	10	20	30	40	50
Water-holding capacity						
Raw emulsion -						
Planimeter	1.57^{a} (.09)	1.43^{b} (.09)	1.36^{bc} (.05)	1.22^{d} (.04)	1.21^{d} (.02)	1.21^{d} (.02)
Grid	1.54^{a} (.08)	1.45^{b} (.10)	1.37^{c} (.04)	1.26^{d} (.07)	1.20^{d} (.02)	1.25^{d} (.03)
Frankfurter -						
Planimeter	1.91^{a} (.06)	1.71^{b} (.06)	1.65^{bc} (.05)	1.44^{d} (.07)	1.43^{de} (.02)	1.36^{e} (.04)
Grid	1.87^{a} (.05)	1.67^{b} (.04)	1.60^{c} (.04)	1.46^{d} (.08)	1.40^{e} (.02)	1.42^{de} (.04)
Expressible juice						
Raw emulsion -						
Planimeter	33.16^{a} (3.75)	27.16^{b} (5.52)	27.41^{b} (4.53)	15.82^{c} (2.89)	16.71^{c} (1.51)	14.78^{c} (1.97)
Grid	34.00^{a} (3.71)	29.84^{b} (5.74)	29.23^{b} (3.97)	18.13^{c} (5.16)	16.95^{c} (1.94)	18.13^{c} (1.97)
Frankfurter -						
Planimeter	37.35^{a} (1.99)	33.21^{ab} (2.70)	32.60^{b} (1.34)	24.89^{c} (2.05)	27.00^{c} (1.38)	23.03^{c} (1.77)
Grid	36.77^{a} (2.85)	35.43^{a} (2.76)	31.67^{b} (.91)	25.42^{c} (3.92)	26.89^{c} (1.20)	27.34^{c} (2.67)

[1]Means for the same measurement with the same superscript letter are not significantly different ($p < .05$); the levels of MPPP were compared by Duncan's multiple range tests and the two area measurements by t-tests.

[2]Standard error of each mean is in parentheses below the mean.

amount of water lost in the stability test or the moisture:protein ratios of raw emulsions (Table 5).

The meat and water areas used for WHC and expressible juice calculations were measured with a plastic grid and compensating polar planimeter. No difference between the two methods of area measurement was observed for WHC or expressible juice determinations on raw emulsions or finished frankfurters (Table 6) when the measurements were compared at each formulation level of MPPP. Simple correlation coefficients between raw WHC and raw expressible juice measurements were greater than r = .88, and correlations were greater than .60 between frankfurter WHC and expressible juice determinations (Table 7). These simple correlation coefficients suggest that the measurement of WHC is comparable to the expressible juice method of measuring the ability of meat to bind or hold water. WHC was shown earlier in this study to influence the yield and fat loss during processing. The simple method of measuring WHC with a plastic grid would enable meat processors to estimate the ability of raw emulsions to bind water more quickly than the measurement of expressible juice.

A significant ($p < .05$) decrease in frankfurter diameter was observed in frankfurters with higher levels of MPPP (Table 4). The 30, 40, and 50 percent levels of MPPP produced frankfurters with smaller diameters, reflecting the greater losses of fat and water during processing. Warner-Bratzler shear force values also decreased with increasing levels of MPPP in frankfurters. Marshall et al. (1977) found that increased levels of MPPP resulted in frankfurters very susceptible to deformation and less desirable in texture. In the

Table 7. Simple correlation coefficients for water-holding capacity and expressible juice percentage on raw and finished frankfurters using grid and planimeter measurements of area

	1	2	3	4	5	6	7	8
1 Raw water-holding capacity, grid	1.00	.94**	.56**	.60**	.95**	.89**	.31	.49**
2 Raw water-holding capacity, planimeter		1.00	.63**	.71**	.88**	.94**	.42*	.63**
3 Finished water-holding capacity, grid			1.00	.85**	.51**	.57**	.87**	.76**
4 Finished water-holding capacity, planimeter				1.00	.57**	.66**	.60**	.93**
5 Raw expressible juice, grid					1.00	.93**	.29	.48**
6 Raw expressible juice, planimeter						1.00	.38*	.60**
7 Finished expressible juice, grid							1.00	.61**
8 Finished expressible juice, planimeter								1.00

*$p < .05$.

**$p < .01$.

present study, the decrease in Warner-Bratzler shear force indicates a softer frankfurter texture. Expressing shear force values as a measurement of fixed shear area did not alter the differences seen for Warner-Bratzler shear values in Table 4. The diameter and shear force were highly correlated with the raw emulsion moisture:protein ratio, amounts of fat and water lost during processing, and raw emulsion WHC (Table 5).

These results indicate that stable, satisfactory emulsions may be produced utilizing MPPP at levels of 30 percent or less. Increased fat and water loss during processing of 40 and 50 percent MPPP formulations resulted in lower yields, smaller frankfurter diameters, and less force required to shear frankfurters. Water-holding capacity may be evaluated by different methods, but formulations with increased levels of MPPP exhibited greater abilities to bind water in raw emulsions and frankfurters. The use of MPPP appears to be acceptable as an alternative source of meat protein in frankfurters, but differences in the water-binding of different formulations deserve further study.

PART II.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF FRANKFURTERS PREPARED WITH DIFFERENT BOWL CUTTERS, ADDED WATER LEVELS, AND CHOPPING TEMPERATURES

INTRODUCTION

Many factors lead to instability of meat sausage emulsions during thermal processing and account for an estimated 2 to 3 percent loss in production (Johnson et al., 1977). Several excellent reviews on meat emulsions have been presented (Saffle, 1968; Gordon, 1969a; Webb, 1974; Schut, 1976), but much of the data has been based upon a model system of emulsion preparation. Commercial emulsification systems are inefficient compared to model systems, and so the factors found to be advantageous in a model system may be of little value in actual meat emulsion production (Saffle, 1968). However, the expense of raw materials, problems of interpreting phenomena observed in the complex meat emulsion, and control of raw materials and variables when a commercial production system is utilized have led to the justifiable widespread use of model systems to determine meat emulsion characteristics (Schut, 1978b).

Morrison et al. (1971) used a model system and found that the ranges of fat and lean could be wide without affecting stability, but the range of water percentage was narrow and critical to stability of emulsions. Brown and Toledo (1975) reported that changes in bound water present in the batter indicated a maximum binding point in the chopping process. Johnson et al. (1977) developed a prototype emulsitator to simulate commercial emulsification procedures and found that emulsions with 20 percent or greater added water resulted in poorer emulsion stability than a 10 percent level of added water. Schut (1978)

concluded that a high degree of water-holding capacity contributes to both water and fat binding.

The stability of emulsions has also been related to final emulsion chopping temperature. Hansen (1960) and Helmer and Saffle (1963) determined the temperature of chopping for optimum water and fat binding to be 15 to 22°C. Schut (1976) reported maximum stability of emulsions at 14°C and concluded that below this temperature fat dispersion was incomplete while above this temperature, fat globules were too finely divided and tended to coalesce upon heating.

This study was designed to incorporate the same meat sources and similar methods of emulsion preparation in comparing bowl cutters of different batch sizes for raw emulsion and frankfurter characteristics. The variables of progressive levels of added ice and different chopping temperatures were included to duplicate industry practices and allow comparison of the two chopper types over a controlled range of conditions. Economy and variable control advantages of the small lab chopper would be useful to meat processors in adapting changes and new products to full-scale production.

EXPERIMENTAL

Frankfurters were manufactured from frozen beef trim, frozen pork trim, and pork backfat in a 2 x 2 x 3 completely randomized design. The two bowl cutters used in this study were a one hp Hobart laboratory chopper with a 45 cm diameter bowl, two blades, and operating speed of 3450 rpm and a VSM-65 Kramer-Grebe bowl cutter with a 65 liter bowl capacity, six blades, and two bowl and four blade operating speeds. Emulsions included 2, 10, or 20 percent added ice and were sampled when emulsion temperatures reached 7.2° and 12.8°C, respectively. Two replications of each of the six formulations (two machines and three levels of added ice) were included in the randomization process.

Frozen beef trimmings, determined to be 10 percent fat with an Anyl-Ray (Kartridg-Pak, Inc.) machine, were stored at -20°C for approximately 30 days and then tempered to 1°C over a period of three days. Pork trim, composed of 20 percent fat as determined with the Anyl-Ray machine, remained in frozen storage at -20°C for approximately 75 days before thawing to 3°C in a 30 hour tempering period. Fresh pork backfat at 4°C was included in formulations to adjust fat content of the meat blocks to 30 percent fat. Formulations for the 4.55 kg batch size used in the Hobart chopper and 13.64 kg batch size for the Kramer-Grebe bowl cutter are shown in Table 8. The beef trim, one-half of the pork trim, salt, and appropriate level of ice were added to the chopper bowl and chopped to 4.4°C in the designated chopper. Lean blends, salt, and ice were chopped at the highest bowl and blade

Table 8. Formulations of frankfurters[a]

Bowl cutter level of added ice (%)	Kramer-Grebe 2	Kramer-Grebe 10	Kramer-Grebe 20	Hobart 2	Hobart 10	Hobart 20
Ingredient						
Beef trim (10% fat) (kg)	6.82	6.82	6.82	2.27	2.27	2.27
Pork trim (20% fat) (kg)	4.26	4.26	4.26	1.42	1.42	1.42
Pork backfat (kg)	2.56	2.56	2.56	.85	.85	.85
Ice (kg)	.27	1.36	2.73	.09	.45	.91
Other ingredients[b] (kg)	.67	.67	.67	.22	.22	.22

[a]Two replication formulations were made for each treatment.

[b]Salt 2.8%, sodium nitrite 156 ppm, sodium erythorbate 580 ppm, onion powder .06%, Heller Premier Weiner Seasoning .5%, and dextrose 1.5% of each formulation.

speeds in the Kramer-Grebe chopper. After reaching 4.4°C, the remaining pork trimmings, pork backfat, and other ingredients were added to the lean mixture and chopping continued to 7.2°C. One-half of the emulsion was removed for sampling and stuffing at this time, and the remaining one-half formulation was chopped to an end-point temperature of 12.8°C. It was noted but not recorded that increased time was required in each chopper to comminute the mix to the desired temperatures as level of added ice increased.

To maintain nearly uniform conditions, all raw emulsions were stuffed into 26 mm cellulose casings with a water-powered piston stuffer (EZ Pak, E. F. Zuber Co.), hand linked and tied (Griffith string tier), weighed, and placed on a smokehouse truck in a 3° cooler. A Maurer smokehouse was employed to cook emulsions to 70°C internal temperature according to the following schedule: 15 minutes at

41 percent R.H. and 54°C, 30 minutes at 63 percent R.H. and 70°C, 10 minutes at 78 percent R.H. and 80°C, and 5 minutes at 80° and 100 percent R.H. followed by a 3 minute cold shower. Frankfurters were chilled to 4° overnight, then weighed and peeled before analysis of the finished product.

Smokehouse yields were calculated by weighing the encased emulsions before smokehouse processing and after overnight chilling of the frankfurters. Moisture, crude fat, and Kjeldahl protein were determined on duplicate samples of each treatment by AOAC procedures (AOAC, 1975). Moisture:protein ratios were calculated from the proximate analyses of raw emulsions and finished frankfurters. A modified Rongey (1965) stability test was employed to estimate fat, water, and total fluid losses during processing. A raw emulsion sample was collected at the correct chopping temperature and approximately 30 g placed into a weighed Wierbicki tube. Tubes were heated for 30 minutes in a 68°C open water bath, cooled for 10 minutes at room temperature, and centrifuged at 250 x G for 20 minutes. Volumes of fat and water lost were expressed as a percentage of initial sample weight. Separation of raw emulsions into fat, soluble, and insoluble phases was observed when a modified centrifugation procedure of Johnson et al. (1977) was employed. Approximately 40 g emulsion samples were placed in a 50 ml plastic centrifuge tube (26 mm diameter) and centrifuged for 3 hours at 18,000 rpm (28,000 x G) in a Beckman Model J-21C centrifuge. After cooling to 4°C, each phase was separated with a spatula, weighed, and expressed as a percentage of initial sample weight. Percent of soluble protein in the water released in the stability test and in the soluble phase obtained in the centrifugation test were determined by the

biuret method of Gornall *et al.* (1949) using bovine serum albumin as a standard.

Water-holding capacity (WHC) of raw emulsions and frankfurters was determined by modifying the procedure of Wierbicki and Deatherage (1958). Samples of .3 g were placed on dried, #1 Whatman filter discs and pressed for 3 minutes in a Carver press at 20670 kilopascals. Meat and juice areas were measured using both a plastic grid (calibrated at 20 dots/6.45 cm^2) and a compensating polar planimeter. Water-holding capacity was expressed as the ratio of juice area to meat area. To determine firmness of the frankfurters, Warner-Bratzler shear force values were obtained on chilled frankfurters after measuring the diameter with a vernier caliper.

Statistical analysis was performed using the SAS analysis of variance procedure (Barr *et al.*, 1976), Duncan's multiple range tests (Duncan, 1955), t-tests (Steel and Torrie, 1960), and stepwise regression procedures (Draper and Smith, 1966). Two replications of each of the six treatments and two samples of each replication were tested and analyzed in a completely randomized fashion for each variable. Tests for homogeneity of variances (Burr, 1974) showed that variances of samples chopped to 5.7°C were greater than samples which were chopped to 12.8°C. The statistical procedures showed that the same differences existed between treatments when the two temperature groups were combined or when each temperature group was analyzed separately.

RESULTS AND DISCUSSION

Mean values for composition of raw emulsions are shown in Table 9. As the level of added ice increased, the percentage of moisture increased significantly ($p < .05$) in the raw emulsions. No differences in moisture percentage were observed for raw formulations between the Hobart cutter and Kramer-Grebe cutter or between the two temperatures at comparable added water levels. Percentage of fat and protein in raw emulsions decreased with increased amounts of added water. An increase in the moisture:protein ratio was also observed with increased added water. Frankfurter composition paralleled that of raw emulsions for moisture, fat, protein, and moisture:protein ratio (Table 10). Moisture and moisture:protein ratio increased and fat and protein content decreased in finished frankfurters as level of water increased. No large differences in composition were noted between the two chopping temperatures, but some of the moisture and fat percentages in frankfurters were significantly different ($p < .05$) between the Hobart and Kramer-Grebe choppers at comparative temperatures and added water levels.

The smokehouse yield of frankfurters is depicted in Figure 4. At 20 percent levels of water, yields were lower than at 2 or 10 percent added water levels. Yields were significantly ($p < .05$) higher (Table 11) for the Kramer-Grebe cutter compared to the Hobart chopper, and chopping to 12.8°C resulted in greater yields than chopping to 7.2°C. Smokehouse yield was significantly ($p < .05$) correlated with raw emulsion composition (Table 13). The modified Rongey procedure

Table 9. Mean values[1] and standard errors of means[2] for influences of cutter, final emulsion temperature, and level of added ice on composition of raw emulsions

Cutter	Temperature (°C)	Level of added water (%)	Raw emulsion			
			Percent moisture	Percent fat	Percent protein	Moisture: protein ratio
Kramer-Grebe	7.2	2	55.71^{de}	25.32^{ab}	13.29^{abc}	4.20^{cd}
		10	58.01^{c}	24.37^{bc}	13.30^{abc}	4.36^{bcd}
		20	61.84^{ab}	22.03^{d}	12.17^{bcd}	5.11^{ab}
Kramer-Grebe	12.8	2	55.41^{e}	25.28^{ab}	13.84^{ab}	4.01^{d}
		10	57.66^{cd}	24.57^{bc}	13.74^{ab}	4.20^{cd}
		20	61.90^{ab}	21.93^{d}	11.34^{d}	5.47^{a}
Hobart	7.2	2	56.03^{de}	25.96^{a}	12.87^{abcd}	4.37^{bcd}
		10	58.46^{c}	23.83^{c}	12.44^{abcd}	4.70^{abcd}
		20	61.28^{b}	22.05^{d}	12.55^{abcd}	4.90^{abc}
Hobart	12.8	2	55.83^{de}	25.89^{a}	14.22^{a}	3.95^{d}
		10	58.85^{c}	24.27^{bc}	12.68^{abcd}	4.65^{bcd}
		20	63.34^{a}	21.56^{d}	11.69^{cd}	5.43^{a}
s.e.m.			.64	.37	.51	.23

[1]Means are averages of two replications (four observations). Means for each variable with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

Table 10. Mean values[1] and standard errors of means[2] for influences of cutter, final emulsion temperature, and level of added ice on composition of frankfurters

Cutter	Temperature (°C)	Level of added water (%)	Frankfurter			
			Percent moisture	Percent fat	Percent protein	Moisture: protein ratio
Kramer-Grebe	7.2	2	51.12^{cd}	27.96^{bcde}	19.98^{a}	3.04^{e}
		10	52.54^{bc}	27.58^{cdef}	15.61^{abc}	3.39^{cde}
		20	55.66^{a}	26.19^{fg}	14.51^{abc}	3.84^{abc}
Kramer-Grebe	12.8	2	50.54^{de}	28.63^{abcd}	16.22^{ab}	3.15^{de}
		10	53.46^{b}	26.45^{efg}	15.72^{abc}	3.42^{cde}
		20	56.52^{a}	25.79^{g}	14.27^{abc}	3.97^{ab}
Hobart	7.2	2	49.38^{e}	29.45^{ab}	16.42^{ab}	3.02^{e}
		10	51.79^{bcd}	28.63^{abcd}	14.17^{bc}	3.65^{bc}
		20	53.05^{b}	27.28^{defg}	14.30^{abc}	3.71^{bc}
Hobart	12.8	2	48.90^{e}	30.23^{a}	15.54^{abc}	3.15^{de}
		10	51.30^{cd}	29.20^{abc}	14.55^{abc}	3.53^{bcd}
		20	55.12^{a}	26.83^{efg}	13.20^{c}	4.18^{a}
s.e.m.			.45	.55	.95	.13

[1]Means are averages of two replications (four observations). Means for each variable with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

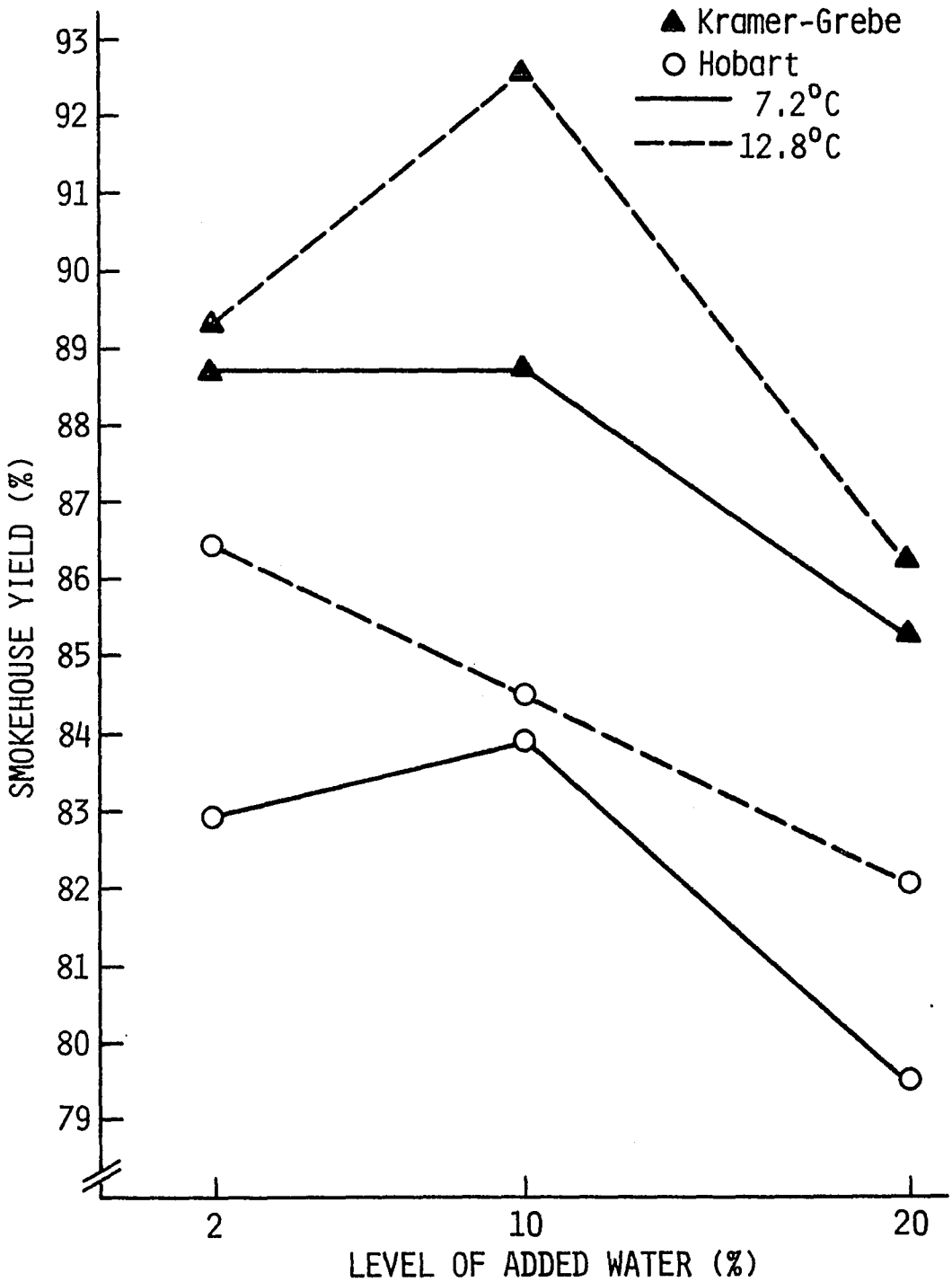


Figure 4. Smokehouse yields for cutter type, chopping temperature, and level of added water

Table 11. Mean values[1] and standard errors of means[2] for influences of cutter, final emulsion temperature, and level of added ice on smokehouse yield and emulsion stability

Cutter	Temperature (°C)	Level of added water (%)	Smokehouse yield (%)	Percent fluid released			Soluble protein (%)
				Water	Fat	Total	
Kramer-Grebe	7.2	2	88.76^{ab}	4.59^{abc}	3.77^{a}	8.36^{a}	2.56^{a}
		10	88.75^{ab}	2.68^{bc}	$.84^{ab}$	3.51^{ab}	5.26^{a}
		20	85.26^{bcd}	3.75^{abc}	$.55^{b}$	4.30^{ab}	2.85^{a}
Kramer-Grebe	12.8	2	89.31^{ab}	2.28^{bc}	$.85^{ab}$	3.13^{ab}	2.28^{a}
		10	92.64^{a}	1.28^{c}	$.21^{b}$	1.49^{b}	2.01^{a}
		20	86.23^{bcd}	2.62^{bc}	$.47^{b}$	3.08^{ab}	1.23^{a}
Hobart	7.2	2	82.90^{cde}	3.31^{abc}	1.21^{ab}	4.51^{ab}	1.71^{a}
		10	83.86^{cd}	5.62^{ab}	1.29^{ab}	6.90^{ab}	3.48^{a}
		20	79.49^{e}	6.37^{a}	1.57^{ab}	7.94^{a}	2.80^{a}
Hobart	12.8	2	86.43^{bc}	2.39^{bc}	$.54^{b}$	2.93^{ab}	2.27^{a}
		10	84.49^{cd}	1.70^{c}	$.40^{b}$	2.10^{ab}	1.36^{a}
		20	82.03^{de}	4.80^{abc}	$.58^{b}$	5.37^{ab}	3.01^{a}
s.e.m.			1.40	1.08	.69	1.90	1.59

[1]Mean values are averages of two replications (four observations). Means for each variable with the same superscript letter are not significantly ($p < .05$) different.

[2]Average standard error of mean for all treatments.

showed more water was lost (Figure 5), but a lesser amount of fat was released (Figure 6) from emulsions with 20 percent added water compared to 2 and 10 percent levels. Emulsions chopped to 12.8°C lost less water, fat, and total fluid (Figures 5, 6, 7) than those emulsions chopped to 7.2°C. Table 11 shows that at the same temperatures and added water levels, fluid losses in the emulsion stability test were not different between the two cutters employed in this study. It appears, however, that at 7.2°C there is a difference in water and fat binding caused by the two cutters as the three fluid loss curves intersected one another instead of paralleling each other as occurred at 12.8°C. Johnson et al. (1977) reported that increases in level of added water above 20 percent caused a decrease in cooked emulsion stability, as did Morrison et al. (1971). Webb (1974) found that cooked stability decreased when chopping temperature exceeded 16.4°C. Hansen (1960) reported that chopping temperatures to 11°C were not high enough to soften the fat and facilitate its dispersion in the protein matrix. A final chopping temperature of 14°C was found to result in maximum emulsion stability by Schut (1976). In the present study, the amount of water released was significantly ($p < .05$) correlated with smokehouse yield ($r = -.49$), but the correlation coefficient between smokehouse yield and amount of fat lost was very low ($r = -.08$) (Table 13).

Centrifugation of raw emulsions at lower speeds, but for a longer time period than that reported by Johnson et al. (1977) resulted in a comparable three phase separation of the emulsions. The percentage of fat phase which separated was similar between cutters and among water levels but was dependent upon final chopping temperature (Figure 8).

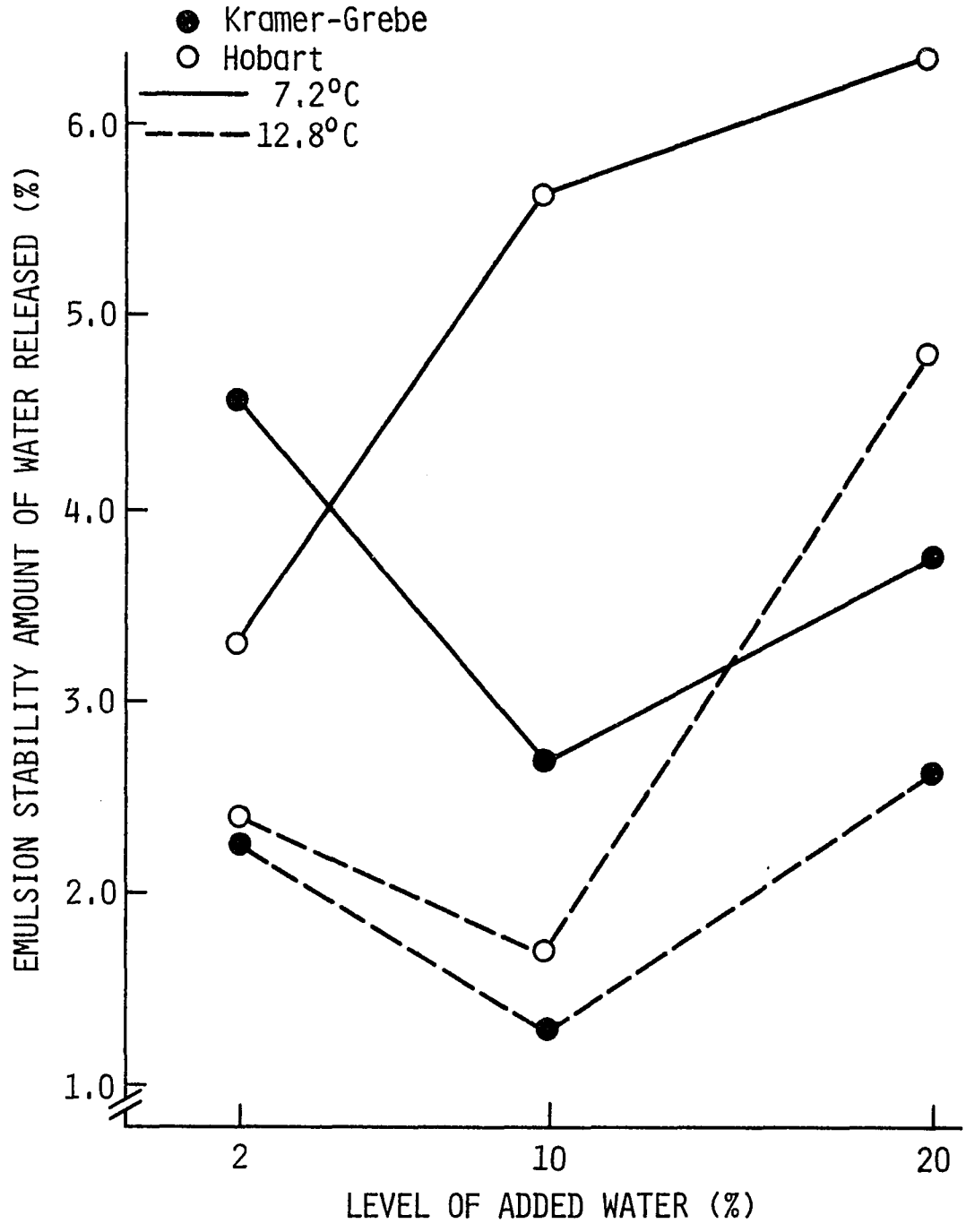


Figure 5. Emulsion stability expressed as percent of water released for cutter type, chopping temperature, and level of added water

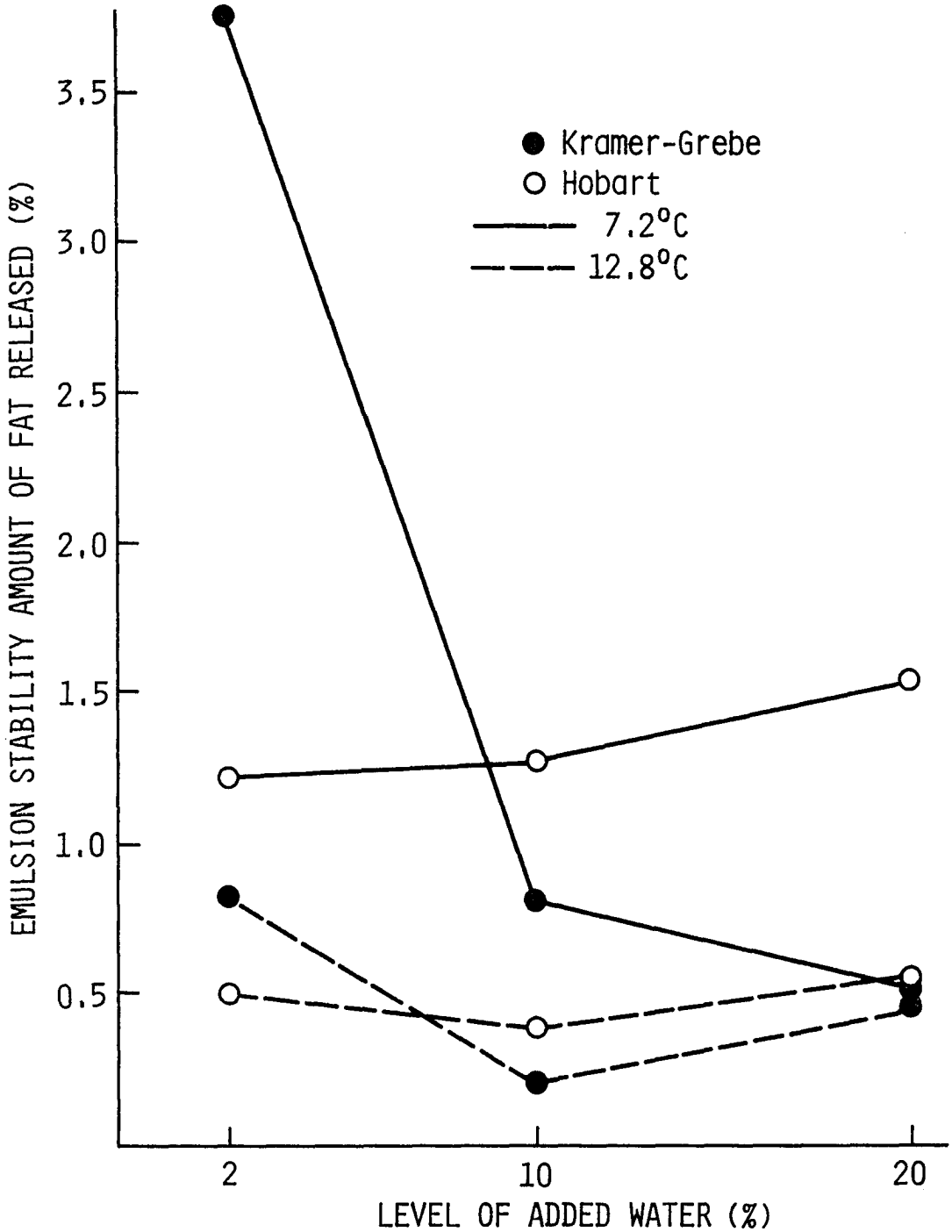


Figure 6. Emulsion stability expressed as percent of fat released for cutter type, chopping temperature, and level of added water

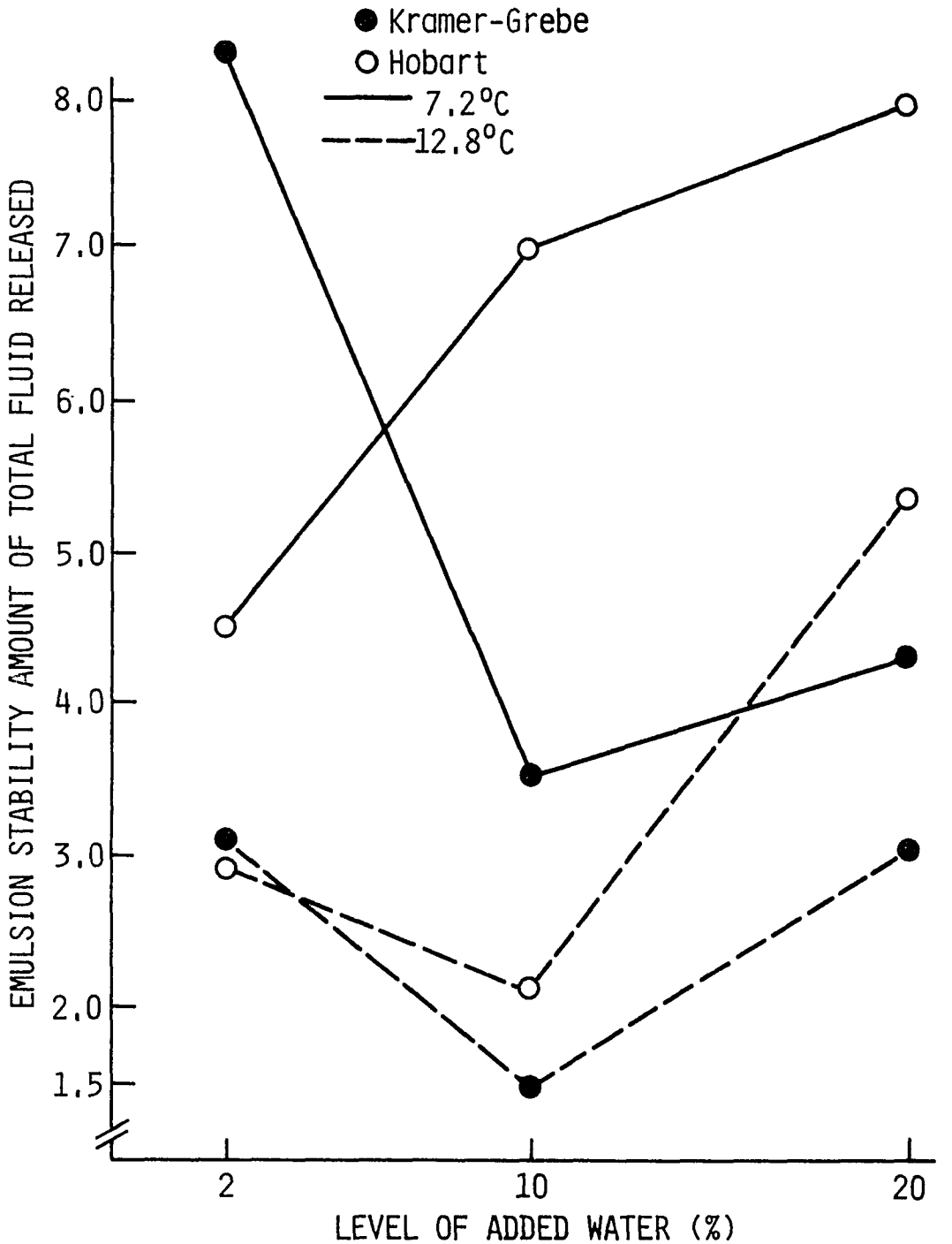


Figure 7. Emulsion stability expressed as percent of total fluid released for cutter type, chopping temperature, and level of added water

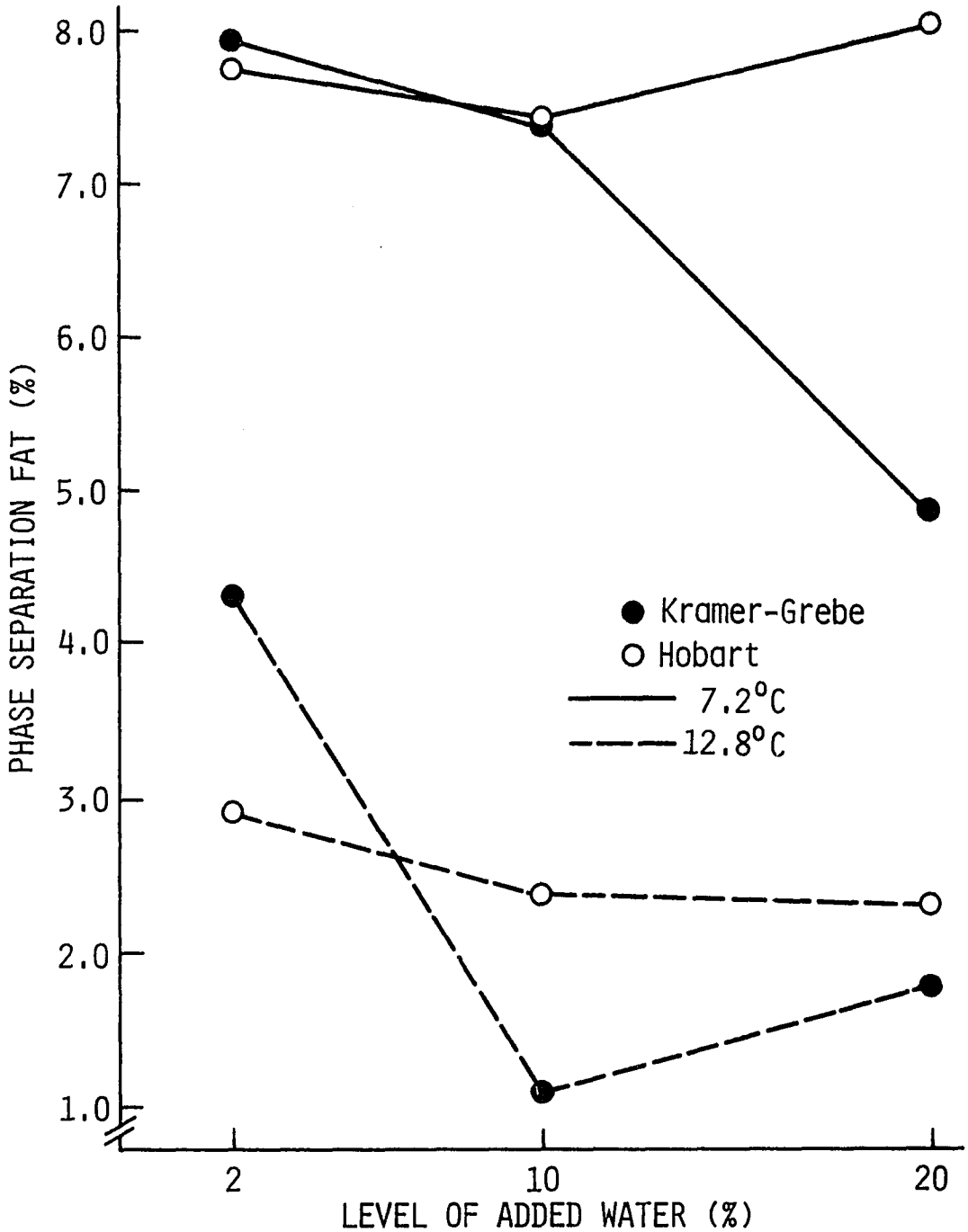


Figure 8. Fat phase of separation for cutter type, chopping temperature, and level of added water

No differences were noted among any of the treatments for the percentage of the soluble phase (Table 12), even though the range was from 1.51 to 14.25 percent of sample weights for the soluble phase separation. A trend for decreased amounts of insoluble phases with higher levels of added water, lower temperatures of chopping, and with the Hobart chopper compared to the Kramer-Grebe cutter was observed (Figure 9), but few differences among treatments for soluble and insoluble phases were found due to the high standard errors associated with those measurements (Table 12). Johnson et al. (1977) showed that the soluble phase percent increased with greater levels of added water. Schut (1978b) showed that the aqueous or fat layer decreased as chopping continued, while the soluble fraction increased and the residue or insoluble phase remained constant.

The fat phase separated by centrifugation was not highly correlated with smokehouse yield or raw composition of emulsions (Table 13), but the soluble and insoluble phases were highly correlated with yield, raw composition, and raw moisture:protein ratio. A correlation coefficient of -.42 between cooked emulsion stability and the soluble phase was found by Johnson et al. (1977). The fat phase was highly correlated with water and fat released in the emulsion stability test (Table 13) in the present study. The soluble phase and insoluble phase were inversely related ($r = -.92$), and both phases were significantly ($p < .05$) correlated with the amount of water lost but not the amount of fat lost in the emulsion stability test.

The soluble protein concentration was measured in both the water released in the stability test and the soluble phase of the

Table 12. Mean values[1] and standard errors of means[2] for influences of cutter, final emulsion temperature, and level of added ice on phase separation and protein solubility of raw emulsions

Cutter	Temperature (°C)	Level of added water (%)	Percent phase separation			Soluble protein (%)
			Fat	Soluble	Insoluble	
Kramer-Grebe	7.2	2	7.93[a]	2.61[a]	87.97[ab]	26.61[a]
		10	7.32[a]	2.13[a]	85.23[ab]	15.04[ab]
		20	4.86[ab]	13.90[a]	77.76[ab]	5.69[b]
Kramer-Grebe	12.8	2	4.33[ab]	1.51[a]	91.37[a]	13.86[ab]
		10	1.12[b]	2.19[a]	92.48[a]	10.87[ab]
		20	1.78[b]	9.21[a]	84.16[ab]	3.61[b]
Hobart	7.2	2	7.77[a]	5.68[a]	83.44[ab]	11.18[ab]
		10	7.44[a]	10.27[a]	77.80[ab]	9.27[ab]
		20	8.05[a]	14.14[a]	72.46[b]	11.00[ab]
Hobart	12.8	2	2.92[b]	3.00[a]	88.42[ab]	10.16[ab]
		10	2.38[b]	8.92[a]	82.21[ab]	12.18[ab]
		20	2.32[b]	14.25[a]	76.85[ab]	1.75[b]
s.e.m.			1.19	4.46	6.19	5.75

[1]Mean values are averages of two replications (four observations). Means for each variable with the same superscript letter are not significantly ($p < .05$) different.

[2]Average standard error of mean for all treatments.

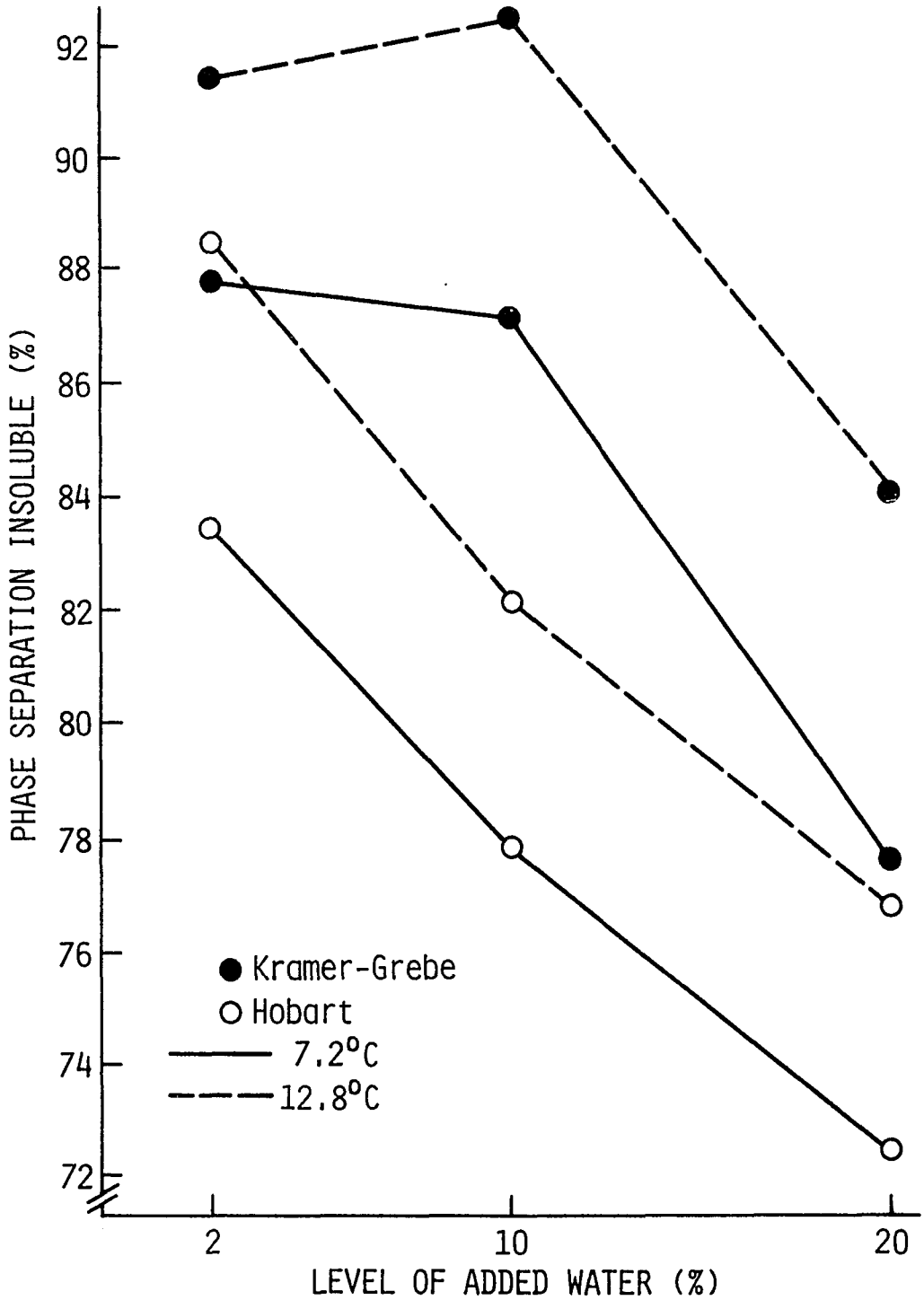


Figure 9. Insoluble phase of separation for cutter type, chopping temperature, and level of added water

Table 13. Simple correlation coefficients for chemical and physical characteristics of raw emulsions and frankfurters

	1	2	3	4	5	6
1 Smokehouse yield	1.0	-.46*	-.42*	.45*	-.48*	-.49*
2 Raw moisture		1.0	-.96**	-.79**	.92**	.26
3 Raw fat			1.0	.76**	-.88**	-.37
4 Raw protein				1.0	-.96**	-.15
5 Raw moisture: protein ratio					1.0	.19
6 Emulsion stability water released						1.0
7 Emulsion stability fat released						
8 Fat phase						
9 Soluble phase						
10 Insoluble phase						
11 Soluble protein in soluble phase						
12 Raw water-holding capacity						
13 Warner-Bratzler shear force						
14 Frankfurter diameter						

*$p < .05$.

**$p < .01$.

7	8	9	10	11	12	13	14
-.08	-.30	-.50*	.54**	.13	-.61**	-.25	.60**
-.25	-.27	.53**	-.42*	-.47*	.85**	.36	-.47*
.15	.18	-.55**	.42*	.39	-.84**	-.30	.39
.18	.13	-.43*	.35	.32	-.74**	-.26	.30
-.22	-.22	.49*	-.40*	-.41*	.83**	.33	-.38
.58**	.64**	.46*	-.56**	.20	.38	.30	-.12
1.0	.66**	-.06	-.12	.79**	.22	.02	.05
	1.0	.10	-.36	.48*	-.10	.13	.05
		1.0	-.92**	-.48*	.51*	.56**	-.11
			1.0	.31	-.48*	-.74**	.07
				1.0	-.44*	-.20	.09
					1.0	.44*	-.38
						1.0	.11
							1.0

centrifugation separation. The treatments showed no differences for the soluble protein in the water released due to the high standard error of the means (Table 11). Soluble protein in the soluble phase separated (Figure 10) showed no definite trends relating to cutter type, temperature, or added water level. With both 7.2 and 12.8°C temperatures for the Kramer-Grebe cutter, soluble protein percent decreased with level of added water. No differences in soluble protein concentration were observed with the Hobart chopper, however (Table 12). The soluble protein percent was highly correlated with stability of fat released and the fat and soluble phases separated (Table 13), but was not strongly related to yield, amount of water released, or the insoluble phase. There were high correlations observed between the soluble protein and the raw moisture composition and moisture:protein ratio (Table 13). Johnson et al. (1977) recorded higher soluble protein concentrations and also higher total soluble protein concentrations with increased levels of added water. In that study, soluble protein concentration did not appear to contribute greatly to cooked emulsion stability, although the amount of total soluble protein was related to cooked stability (Johnson et al., 1977).

Water-holding capacity was determined for raw emulsions and frankfurters in the present study. Water-holding capacity (WHC) decreased with greater levels of added water in Figure 11, where values closer to 1.0 indicate a greater WHC or ability to retain water. Raw emulsions prepared in the Kramer-Grebe chopper had greater WHC than emulsions prepared in the Hobart chopper, although the differences were not large between the two chopper types at similar temperature

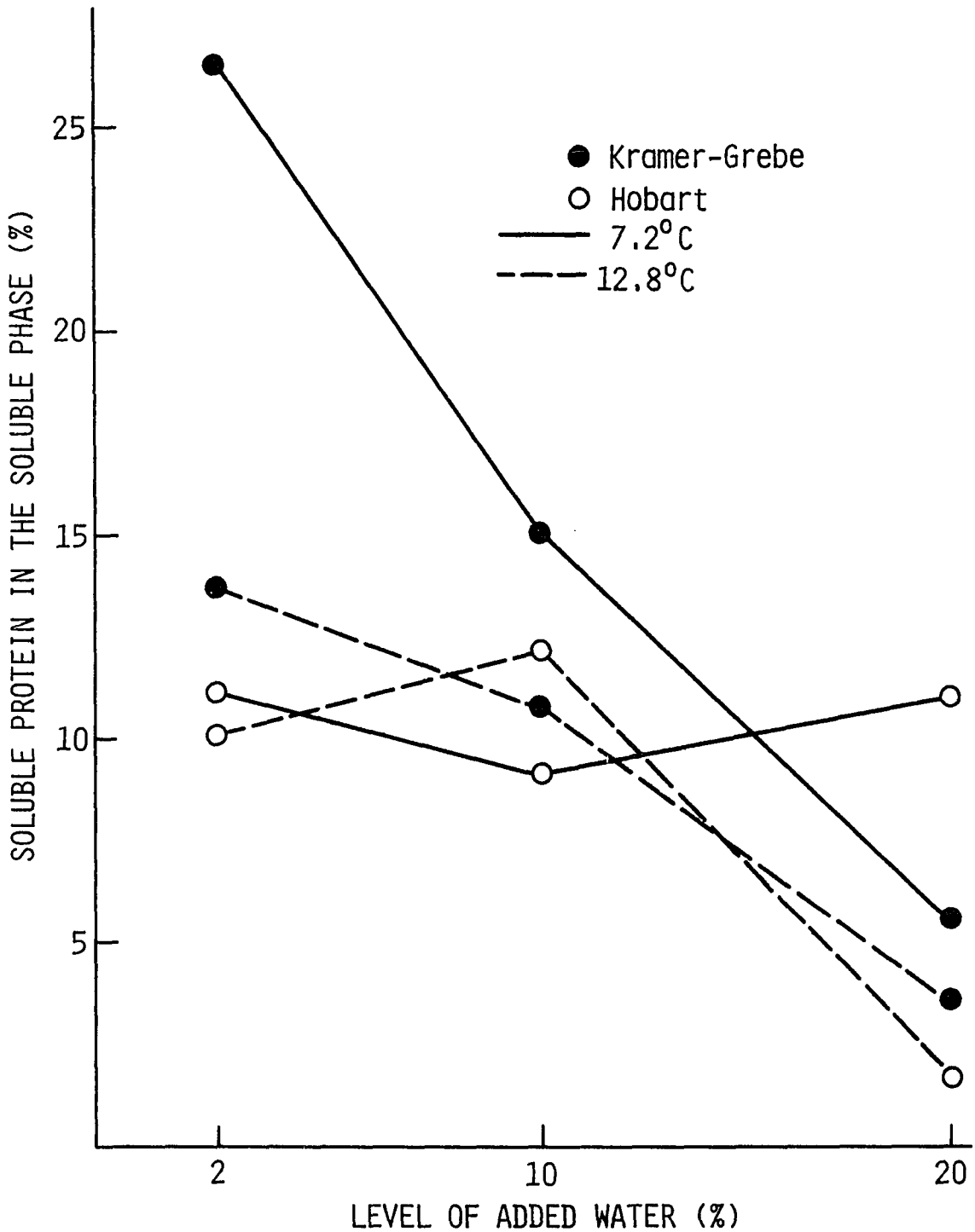


Figure 10. Percentage of soluble protein in the soluble phase of separation for cutter type, chopping temperature, and level of added water

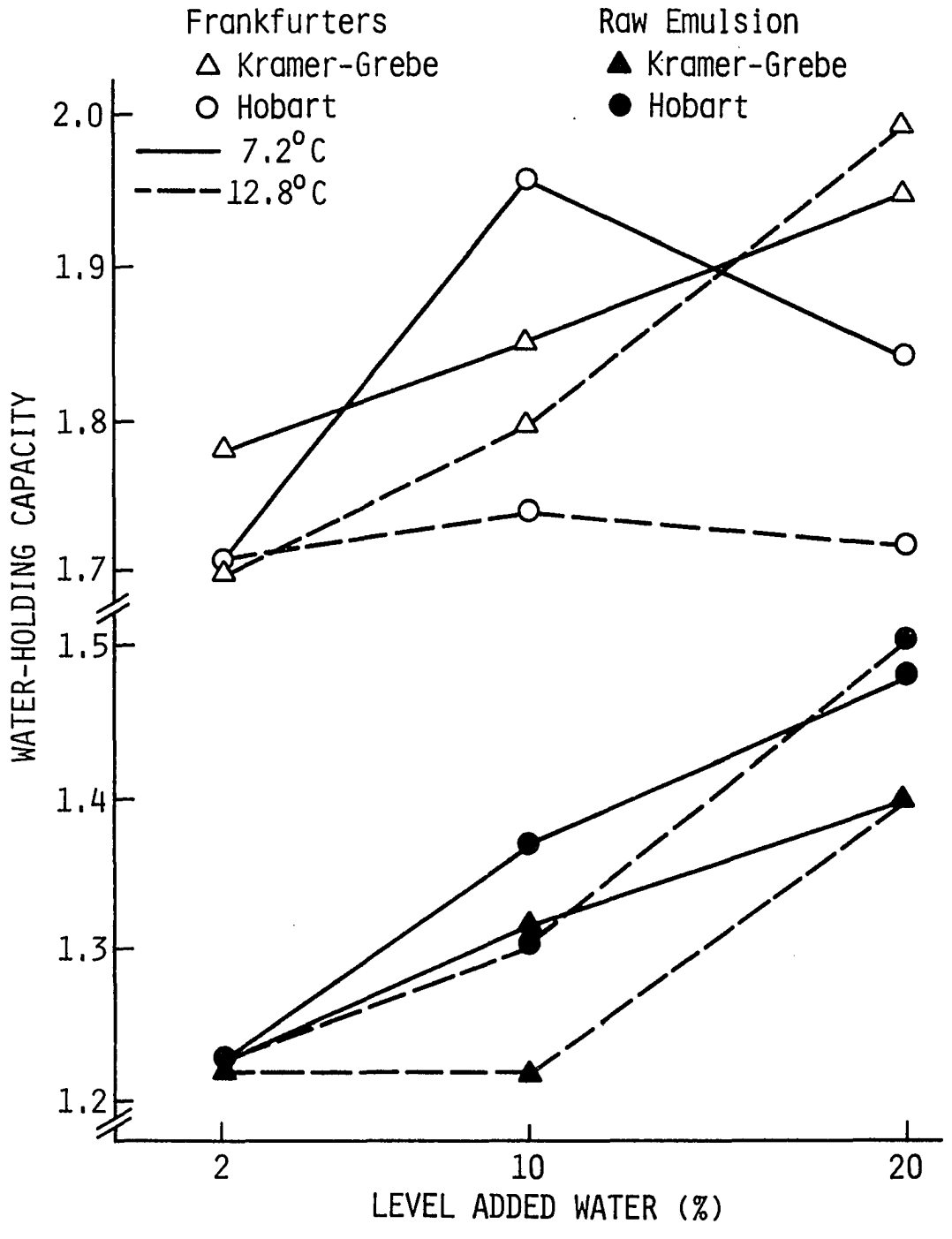


Figure 11. Water-holding capacity by grid area measurement of raw emulsions and frankfurters for cutter type, chopping temperature, and level of added water

and added ice levels (Table 14). Temperature of chopping and level of added water influenced WHC of finished frankfurters (Table 14). Frankfurters which were prepared by chopping to 12.8°C retained more water than frankfurters which had been prepared by chopping to 7.2°C (Figure 11). Frankfurters prepared with the Kramer-Grebe bowl cutter had a lower WHC with increased water levels, while Hobart preparation of frankfurters showed greater WHC at 10 percent added water than at 2 or 20 percent levels. Raw emulsion WHC was very highly correlated ($p < .01$) with smokehouse yield, raw emulsion composition, and moisture: protein ratio and was also highly correlated ($p < .05$) with the soluble and insoluble phases and percent soluble protein in the soluble phase (Table 13). It should be noted that no significant differences in WHC due to method of area measurement were seen (Table 14), allowing the simpler and more rapid grid area measurement to be made instead of the planimeter area measurement.

Firmness of frankfurters is an important physical trait. No differences in firmness as measured by a Warner-Bratzler shear press were found between treatments (Table 15). However, there were variations in the diameters of the chilled frankfurters. Frankfurters which had been prepared in the Kramer-Grebe cutter were slightly larger in diameter than those prepared in the Hobart chopper. Chopping emulsions with increased levels of added ice also caused the frankfurter diameter to decrease (Table 15). Expressing the shear force on a diameter basis did not appreciably change the firmness observed. It was shown by Johnson *et al.* (1977) that penetrometer measurements would detect small differences in firmness, and they reported cooked emulsions

Table 14. Mean values[1] and standard errors of means[2] for influences of cutter, final emulsion temperature, and level of added ice on water-holding capacity of raw emulsions and frankfurters

Cutter	Temperature (°C)	Level of added water (%)	Raw emulsion		Frankfurter	
			WHC[3]	WHC[4]	WHC[3]	WHC[4]
Kramer-Grebe	7.2	2	1.23^{e}	1.22^{ce}	1.78^{abc}	1.72^{ab}
		10	1.32^{cde}	1.36^{abc}	1.85^{abc}	1.86^{ab}
		20	1.40^{abc}	1.40^{ab}	1.95^{ab}	1.98^{a}
Kramer-Grebe	12.8	2	1.27^{de}	1.23^{ce}	1.70^{c}	1.70^{bc}
		10	1.22^{e}	1.22^{ce}	1.79^{abc}	1.79^{ab}
		20	1.41^{abc}	1.41^{ab}	1.97^{a}	1.99^{a}
Hobart	7.2	2	1.26^{de}	1.29^{bce}	1.71^{c}	1.78^{ab}
		10	1.37^{bcd}	1.36^{abc}	1.96^{a}	1.89^{ab}
		20	1.48^{ab}	1.46^{a}	1.84^{abc}	1.89^{ab}
Hobart	12.8	2	1.29^{cde}	1.27^{bce}	1.70^{c}	1.62^{b}
		10	1.31^{cde}	1.29^{bc}	1.74^{abc}	1.78^{ab}
		20	1.51^{a}	1.49^{a}	1.72^{bc}	1.78^{ab}
s.e.m.			.04	.05	.07	.09

[1]Means are averages of two replications (four observations). Means for each variable with the same superscript letter are not significantly different ($p < .05$). Means for grid area measurement and planimeter area measurement are not significantly different ($p < .05$) if accompanied by the same superscript letter for raw emulsion or frankfurter water-holding capacity (WHC) as compared by t-tests.

[2]Average standard error of mean for all treatments.

[3]WHC determined by grid area measurement.

[4]WHC determined by planimeter area measurement.

Table 15. Mean values[1] and standard errors of means[2] for influences of cutter, final emulsion temperature, and level of added ice on physical characteristics of raw emulsions and frankfurters

Cutter	Temperature (°C)	Level of added water (%)	Frankfurter diameter (mm)	W-B shear force (kg)	Shear force/area (kg/mm)
Kramer-Grebe	7.2	2	22.18^{a}	2.20^{a}	.10^{bc}
		10	21.53^{a}	2.56^{a}	.12^{abc}
		20	21.52^{a}	2.79^{a}	.13^{abc}
Kramer-Grebe	12.8	2	22.13^{a}	2.09^{a}	.09^{c}
		10	21.24^{ab}	2.33^{a}	.11^{abc}
		20	20.78^{ab}	2.50^{a}	.12^{abc}
Hobart	7.2	2	20.66^{ab}	2.33^{a}	.11^{abc}
		10	21.77^{a}	2.72^{a}	.12^{abc}
		20	19.16^{b}	2.78^{a}	.15^{a}
Hobart	12.8	2	21.47^{a}	2.71^{a}	.13^{abc}
		10	20.69^{ab}	2.73^{a}	.13^{abc}
		20	20.11^{ab}	2.82^{a}	.14^{ab}
s.e.m.			.70	.86	.04

[1]Means are averages of two replications (four observations). Means for each variable with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

became less firm as the level of added water was increased. Simon et al. (1965) had previously shown that penetrometer readings were highly correlated with taste panel evaluations of tenderness. It was reported by Morrison et al. (1971) that physical property scores for resilience, binding, and firmness as rated by a subjective panel decreased as the level of added water increased. In the present study, Warner-Bratzler shear force was significantly ($p < .01$) correlated with percentages of soluble and insoluble phases and was also related to raw WHC (Table 13). Frankfurter diameter was highly correlated ($r = .60$) to smokehouse yield but was less strongly related to the amount of raw moisture in the emulsion formulation.

Stepwise regression equations were derived for the variables smokehouse yield and total fluid released in the stability test (Table 16) to determine the factors affecting yield and stability. Emulsion stability was affected most by the amount of fat separated during centrifugation ($R^2 = .524$), while smokehouse yield was influenced strongly by the raw emulsion WHC ($R^2 = .366$). By including percent fat in the raw emulsion along with the percent fat phase, 61.4 percent of the variation in emulsion stability was explained. As Table 16 shows, greater R^2 values were obtained as more variables were included in the regression analysis. An R^2 value of .833 was obtained when the water, fat, and protein composition of the raw emulsion were included with the amount of added water, fat and soluble phases, and amount of soluble protein in the regression equation for emulsion stability. The fat phase and raw emulsion WHC combined to account for almost 50 percent of the variation in smokehouse yield. As more variables

Table 16. Coefficients of determination (R^2) for prediction of emulsion stability and smokehouse yield

Variables in equation for emulsion stability[a]	R^2	Variables in equation for smokehouse yield[b]	R^2
Fat phase[c]	.524	WHC[g]	.366
Raw fat[d], fat phase	.614	Fat phase[c], WHC	.496
Sol prot[e], raw fat, fat phase	.708	Sol phase[c], fat phase, WHC	.522
Sol phase[c], sol prot, raw fat, fat phase	.757	Raw fat[d], sol phase, fat phase, WHC	.546
Raw prot[d], sol phase, sol prot, raw fat, fat phase	.784	Raw water[d], raw fat, sol phase, fat phase, WHC	.595
Added ice[f], raw prot, sol phase, sol prot, raw fat, fat phase	.824	Insol phase[c], raw water, raw fat, sol phase, fat phase, WHC	.722
Raw water[d], added water, raw prot, sol phase, sol prot, raw fat, fat phase	.833	Sol prot[e], insol phase, raw water, raw fat, sol phase, fat phase, WHC	.732

[a]Total emulsion stability as percent of total fluid released.

[b]Smokehouse yield of frankfurters as percent of encased emulsion weight.

[c]Fat, soluble, and insoluble phases as percent of centrifugation separation.

[d]Raw emulsion moisture, fat, and protein percent composition.

[e]Soluble protein as percent of soluble phase separation.

[f]Level of added ice as 2, 10, or 20 percent.

[g]Water-holding capacity of raw emulsions with grid area measurement.

were added in the stepwise regression procedure, the coefficient of determination became greater. Slightly more than 73 percent of the variation in smokehouse yield was explained by differences in the raw WHC, fat and moisture composition, phase separation into fat, soluble, and insoluble portions, and the percentage soluble protein in the soluble phase. It may be seen that the emulsion stability test utilized in this study does not totally simulate conditions in the smokehouse as the same variables did not affect both stability and yield. Raw emulsion protein percentage and level of added water influenced stability, while smokehouse yield prediction variables included the insoluble phase and WHC of the raw emulsion. Complete prediction equations were not given for smokehouse yield and emulsion stability as the equations apply only to the boundaries used in this study.

Many factors influence stability and physical properties of frankfurters, as shown in this study. The ability of the protein matrix to hold water was influenced by added ice level, cutter type, and temperature of comminution. As the percent of soluble phase increased and the percentage of insoluble phase decreased with increased added water levels, the amount of soluble protein decreased for the Kramer-Grebe cutter. Studies with model systems (Morrison et al., 1971; Johnson et al., 1977; and Gillett et al., 1977) have suggested that portions of the protein become insoluble during emulsification. The data of the present study suggest that variables of composition and comminution practices influence the amount of insoluble portion separated, which in turn has an effect on emulsion stability. The results shown here agree with the conclusions of Brown and Toledo

(1975) and Schut (1976) that there is maximum water binding present during a point in the emulsification process, but more factors than simple emulsification are involved in the stabilization process in commercial production. It was seen that smaller systems of emulsion preparation are useful for suggesting results in commercial production, but the two systems in this study were not identical in manufacture of frankfurters.

PART III.

COMPOSITION OF MECHANICALLY PROCESSED (SPECIES) PRODUCT PRODUCED BY A HYDRAULIC PRESS DEBONER

INTRODUCTION

The USDA has established rules governing the production and use of mechanically processed (species) product (MP(S)P) (Federal Register, 1978). Among the requirements for mechanically processed beef product (MPBP) and mechanically processed pork product (MPPP) are minimum protein content of 14 percent, maximum fat content of 30 percent, maximum calcium level of .75 percent, and maximum bone particle size of .85 mm. Many studies have been conducted on variables affecting MP(S)P, but most have examined the MP(S)P produced by rotary-type mechanical deboners. In this type of mechanical deboning equipment, ground bones are continuously augered past a seiving screen or straining device which separates the bone residue from muscle tissue (Anonymous, 1976). Another type of mechanical deboning machine which has been approved by the USDA relies on hydraulic pressure to force bones and the adhering lean tissue into a seiving device. Goldstrand (1975) reported a difference between the continuous machine type and hydraulic pressure batch type of deboners which are used to produce MP(S)P. The machine utilizing the stationary hydraulic straining device produced MPPP from pork back, neck, ham, and picnic bones, and MPBP from beef chine bones which met the USDA constraints, while one of the two continuous rotary machines did not produce MPPB which met calcium limitations, but it was concluded that the closeness of commercial trimming influenced the composition of MP(S)P more than other variables (Goldstrand, 1975).

Several studies have shown that deboning whole carcasses or wholesale cuts results in suitable MP(S)P (Field et al., 1974a and b; Anderson and Gillett, 1974; and Marshall et al., 1977), but it is still more economical to remove a majority of the muscle tissue by hand boning. Only a few studies have shown that commercially trimmed bones which are then mechanically deboned produce MP(S)P which meets USDA regulations (Goldstrand, 1975; and Field et al., 1975), although there are large amounts of such bones available for deboning (Field, 1976).

Other factors including pressure, temperature, preparation prior to deboning, and processing conditions as well as the type of bones and deboner device influence the characteristics of MP(S)P (Goldstrand, 1975). The present study was conducted to determine characteristics of MP(S)P produced under varying production conditions with a Kartridg-Pak Meat Removal System, a hydraulic press mechanical deboner. Mechanically processed pork product produced under various pressures was examined for yield and chemical composition. Characteristics of MPPP from bones frozen prior to deboning were compared with MPPP from bones processed in a fresh condition. Additionally, commercially trimmed bones from mature and young animals were mechanically deboned to determine the effects of bone type, age, and animal specie on MP(S)P composition.

EXPERIMENTAL

The Kartridg-Pak Meat Removal System used to produce mechanically processed (species) product was loaned by the Kartridg-Pak Corporation, Davenport, Iowa. The bottom straining outlet of the hydraulic cylinder consisted of three concentric stainless steel extrusion rings which served to strain the muscle tissue from the bones. Maximum tolerance between the separating orifice of the extrusion rings and receiver assembly was .23 mm with a maximum of .69 mm distance between the sides of the rings and the stationary receiver assembly where the MP(S)P exited after being removed from the bones. The top straining device was a mesh screen of .5 mm hole openings with a knife blade which rotated in a circular pattern to scrape the surface of the screen. A reinforced plastic hose of 33 mm inside diameter was used to convey the MP(S)P into plastic tubs.

In the first phase of the experiment, trimmed pork backbones from pigs less than six months of age were purchased from a commercial packing company, transported fresh to the meat laboratory, and stored at $3^{o}C$ for 18 hours until being mechanically processed. The bones were pre-broken in a Weiler grinder with a 2.54 cm plate, and then 10 repetitive batches of 1.9 kg each were deboned at the following pressures: 20670, 24115, 27560, or 31005 kilopascals (10 kPa = 1 newton/cm^2). In the second phase of the experiment, pork neck, back, pelvic, and femur bones of market weight pigs (less than 115 kg) and heavy sows (greater than 225 kg) were obtained from a composition study in the meat laboratory. The pork bones were commercially trimmed

of lean tissue, ground through the Weiler grinder, and then stored frozen for two weeks at -20°C. Young pork back, neck, pelvic, and femur bones (from pigs less than eight months of age) which were commercially trimmed and young steer neck, back, and rib bones (from steers less than 30 months of age) which had been scraped of all visible lean were obtained fresh from the composition study and ground in the Weiler grinder. Batches of 1.8 kg and an operating pressure of 27560 kPa were used when the fresh and frozen bones were processed through the KP deboner, but the frozen bones were allowed to thaw to 0°C before deboning. Immediately following the deboning of each batch of bones, the MP(S)P was frozen in a cryogenic tunnel and stored at -20°C for subsequent sampling.

Yield of deboned meat product was calculated by difference after weighing the bones prior to deboning and the resulting bone puck residue after deboning. Moisture, crude fat, Kjeldahl protein, and ash were determined on MP(S)P samples by AOAC (1975) procedures. Calcium determination was made according to the procedure of Ewan et al. (1979) on a Perkin-Elmer atomic absorption spectrophotometer. Percentage of crude bone was obtained by following the papain digestion, acetone:carbon tetrachloride flotation procedure of Hill and Hites (1968). Micrographs of bone particles were taken with a Polaroid camera (8.26 x 10.8 cm) mounted on a Balplan (Bausch and Lomb) phase contrast microscope.

Statistical analysis was performed on data using the SAS analysis of variance procedure (Barr et al., 1976), Duncan's multiple range tests (Duncan, 1955), and stepwise regression analysis (Draper and Smith, 1966).

RESULTS AND DISCUSSION

The bone temperatures prior to deboning, MPPP temperatures after deboning, and yields are shown in Table 17. As the amount of pressure applied to the bones increased, the yield of MPPP also increased in a linear fashion. Bones at the lower pressures were processed at 10 to

Table 17. Temperatures and yields of MPPP with different deboning pressures

Pressure (kPa)	Bone temperature (°C)	MPPP temperature (°C)	Yield of MPPP (%)
20670	10.0	15.7	37.1
24115	10.0	15.9	41.7
27560	12.8	18.3	42.8
27560	3.3	14.4	42.1
31005	3.3	14.4	45.7

12.8°C, while the higher pressures were used on bones at 3.3°C. Similar temperature rises of 5 to 11°C were observed during the deboning procedure for the pressures applied in the hydraulic press deboner. Field et al. (1975) reported a range of 6 to 18°C temperature rise during deboning of pork bones with a rotary deboner. Field et al. (1974a) found that increasing the pressure exerted on bones during deboning raised yields from mutton carcasses and lamb cuts, which resulted in decreased moisture and increased fat content in the MP(S)P. Trends in the present study show the moisture, fat, and protein percentages of MPPP remained constant over the range of pressures which

were tested (Figure 12). Analysis of variance (Table 18) indicated no significant differences were noted between pressures or between the two types of MPPP outlets which were used for percentages of fat, moisture, or protein. It should be noted that the range of protein was from 11.77 to 14.20 percent and range of fat was 26.25 to 32.19 percent for the MPPP samples, which indicates the pork backbones were trimmed closely by the commercial packing company but the MPPP would meet or was close to meeting the compositional limits established by the USDA.

Table 18. Sums of squares from analysis of variance for composition of MPPP produced with different pressures and outlet types

Source[a]	d.f.	Composition percentage				
		Moisture	Fat	Protein	Calcium	Bone
Pressure (P)	3	19.228	26.225	7.432	.197	2.394**
Outlet (O)	1	.214	.677	1.789	.058	.109**
P x O	3	26.761	33.031	1.629	.004	.005
Error	8	36.486	30.769	7.627	.207	.091
Total	15	82.688	90.701	18.478	.466	2.599

[a]Model was μ(mean) = $P_i + O_j + PxO_{ij} + E_{ijk}$ where

P = Effect of pressure with KP deboner (20670, 24115, 27560, or 31005 kPa), i = 1-4
O = Effect of outlet type for MPPP (top or bottom), j = 1,2
PxO = Interaction of main effects.
E = Error
k = Observations 1 and 2.

**$p < .01$.

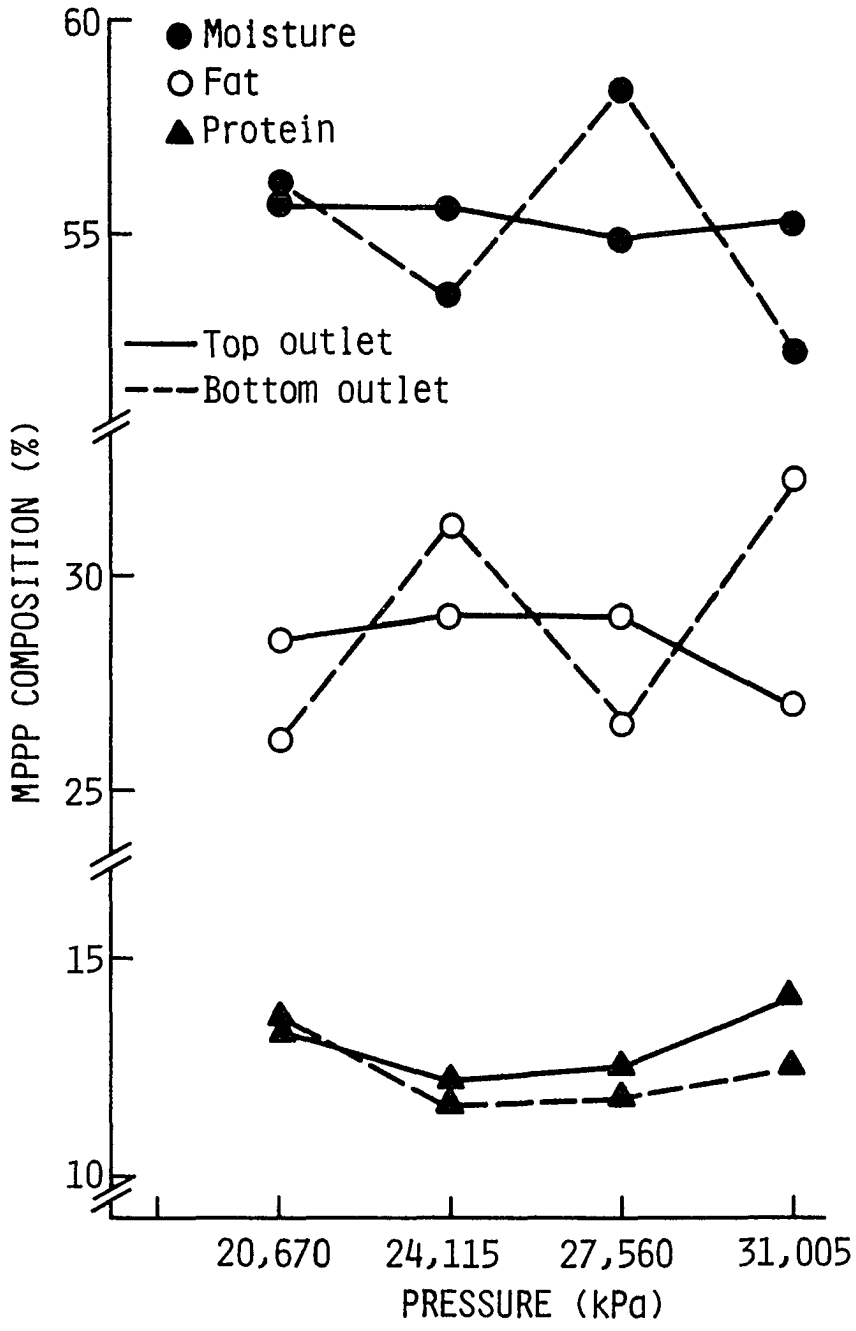


Figure 12. Chemical composition of mechanically processed pork product with increased pressures of deboning

Calcium content and percentage of crude bone were also measured in the present study (Figure 13). The level of calcium increased slightly with increased deboning pressures as did the amount of crude bone. At the highest pressure of 31005 kPa, however, a decrease in both calcium levels and amount of bone recovered was observed, suggesting that a maximum amount of bone was forced into the MPPP at 27560 kPa and more pressure caused increased bone marrow to be present in the deboned meat. It had been previously reported (Field et al., 1974a) that calcium percentage increased with increased pressure in a continuous rotary deboner for mutton carcasses and lamb parts, but the percentage of bone decreased for mutton carcasses and lamb necks, breasts, and shoulders and increased for lamb legs as pressure was increased. Table 18 shows that in the present study no differences in calcium percentage were present between pressures or outlet types, but the pressure and outlet types were significantly different ($p < .05$) in the amount of crude bone forced into the MPPP during deboning. Simple correlation coefficients (Table 19) revealed a high relationship ($r = 0.59$) between percentage of bone and percentage of calcium in MPPP produced with different pressures and outlet types. However, calcium accounted for only 34.4 percent of the variation in bone content (Table 25) and the addition of pressure and outlet location to the regression equation did not explain a greater amount of the variation in bone content. Micrographs (30X) of bone particles recovered from MPPP showed no great differences in size due to pressure or outlet type (Figure 14). The horizontal black line shown on Micrograph A in Figure 14 represents a distance of 1 mm. The bone

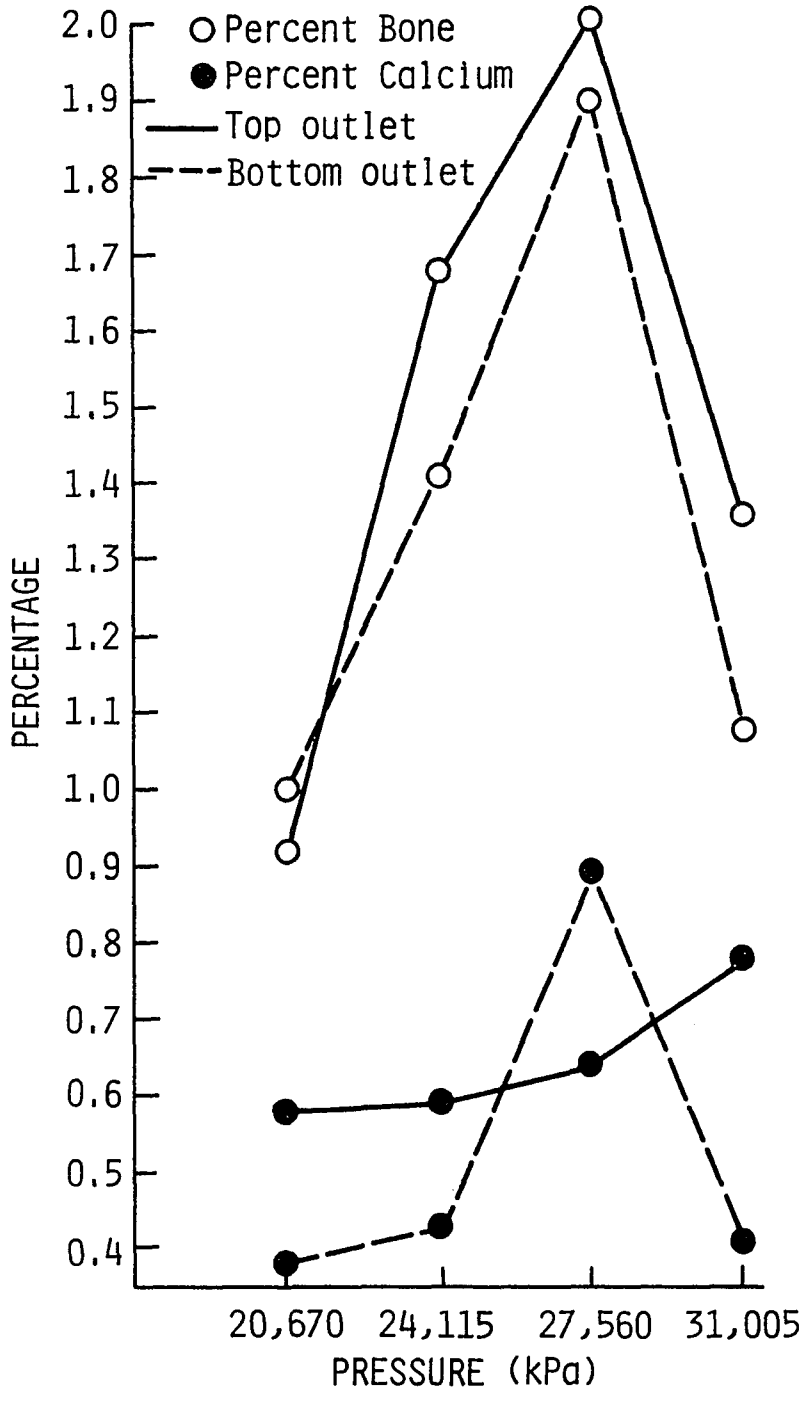


Figure 13. Percentage of crude bone and calcium in mechanically processed pork product with increased pressures of deboning

Table 19. Simple correlation coefficients for composition of MPPP produced with different pressures and outlet types

Composition percentage	Composition percentage					
	Moisture	Fat	Protein	Calcium	Bone	Yield
Moisture	1.00	-.92**	.02	.49	.23	-.27
Fat		1.00	-.29	-.40	-.10	.36
Protein			1.00	.00	-.41	.12
Calcium				1.00	.59*	.34
Bone					1.00	.39
Yield						1.00

*$p < .05$.

**$p < .01$.

particles were more rounded when produced from the top as compared to the bottom outlet, suggesting that the design of the bottom outlet, with the ring separation apparatus, allowed longer and more splintered bone particles, in larger proportions than allowed (Federal Register, 1978), to be forced into the MPPP. All of the bone particles show the characteristic amorphous, irregular structure due to mechanical deboning, as was also observed by Froning (1979) when bone particles from various poultry meat products were examined and Field et al. (1977) who processed beef neck bones through a continuous deboner.

A summary of the data collected in the second phase of the study is presented in Table 20. The comparison of mature and young pork back and pelvic bones showed back bones yielded more MPPP than pelvic bones at both ages of bone. Young pork bones yielded more MPPP than

Figure 14. Photomicrographs of bone particles isolated from MPPP produced with different pressures

A. Pork back bones, 27560 kPa, bottom outlet, 30X magnification

B. Pork back bones, 20670 kPa, top outlet, 30X magnification

C. Pork back bones, 31005 kPa, top outlet, 30X magnification

D. Pork back bones, 24115 kPa, bottom outlet, 30X magnification

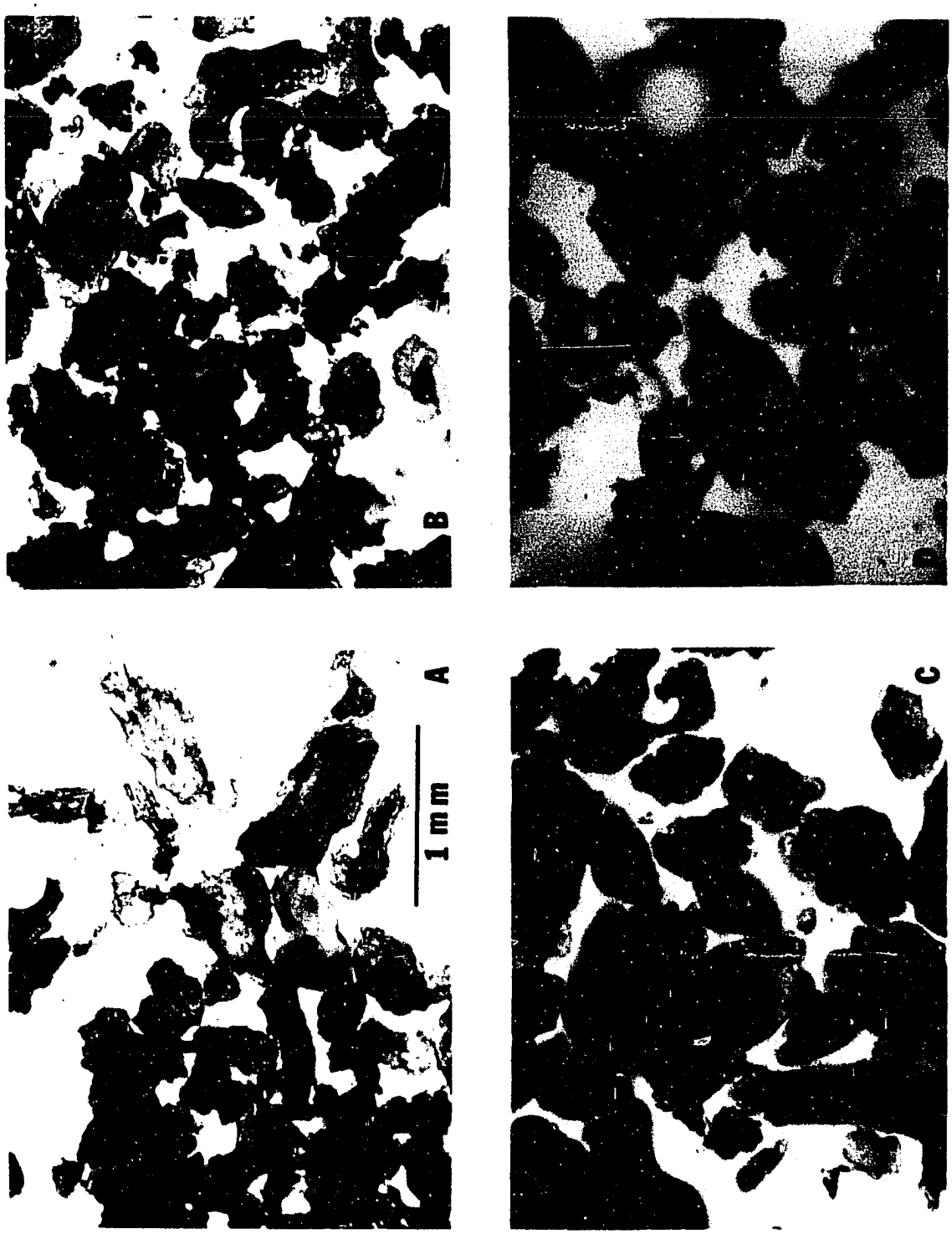

B
A
1 mm
C

Table 20. Mean values[1] and standard error of means[2] for composition of MP(S)P produced with different species, storage conditions, bone types and ages, and outlet types

Specie	Bone age and storage	Bone type	Bone temp. (°C)	MP(S)P temp. (°C)	MP(S)P yield (%)	Outlet location
Pork	Mature frozen	Back	0.0	5.6	33.86	Top
						Bottom
		Pelvic	-1.1	7.8	22.29	Top
						Bottom
Pork	Young frozen	Back	1.1	5.0	41.48	Top
						Bottom
		Pelvic	0.0	5.0	25.83	Top
						Bottom
	Fresh	Back	4.4	15.6	43.22	Top
						Bottom
Beef	Young fresh	Back	10.6	15.0	18.09	Top
						Bottom
s.e.m.						

[1]Means are averages of two observations. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Standard errors of means are averaged over all means for each compositional trait.

Percent composition					
Moisture	Fat	Protein	Ash	Calcium	Crude bone
59.31^{a}	22.65^{d}	17.31^{a}	3.51^{c}	$.22^{ab}$	$.98^{ab}$
59.09^{ab}	23.00^{cd}	14.16^{abc}	3.17^{cd}	$.13^{ab}$	1.05^{ab}
56.91^{ab}	28.40^{abcd}	10.69^{c}	3.28^{c}	$.23^{ab}$	1.91^{a}
58.60^{ab}	26.43^{bcd}	11.67^{bc}	3.08^{cd}	$.16^{ab}$	$.37^{b}$
55.06^{abc}	29.35^{abc}	15.17^{ab}	2.42^{d}	$.08^{b}$	$.40^{b}$
56.71^{ab}	26.57^{bcd}	14.77^{ab}	2.42^{d}	$.06^{b}$	$.40^{b}$
57.41^{ab}	24.86^{cd}	13.96^{abc}	3.05^{cd}	$.20^{ab}$	$.99^{ab}$
58.65^{ab}	24.68^{cd}	14.18^{abc}	3.03^{cd}	$.29^{a}$	$.61^{b}$
54.79^{bc}	28.66^{abcd}	12.54^{bc}	8.93^{a}	$.10^{b}$	$.90^{ab}$
52.18^{c}	31.96^{ab}	14.34^{ab}	8.12^{b}	$.13^{ab}$	$.84^{b}$
51.93^{c}	33.74^{a}	13.31^{bc}	8.97^{a}	$.14^{ab}$	1.25^{ab}
51.45^{c}	33.34^{a}	14.40^{bc}	8.79^{ab}	$.12^{b}$	$.83^{b}$
1.22	1.39	.69	.24	.05	.23

mature pork bones of the same type. There were no differences in moisture and fat composition of the MPPP produced from bones of different types and ages (Table 21), although a significant ($p < .01$) interaction of bone type and bone age effects on fat were observed. Protein percentage in the MPPP depended significantly ($p < .01$) upon the type of bones and interactions between bone type and age and between bone type and the outlet type used to separate MPPP from the bone were present. The bone age affected the amount of ash present in MPPP, while calcium percentage was influenced by the type, back or pelvic, of bones processed through the deboner. The amount of bone separated from MPPP varied highly ($p < .05$) with the type of outlet used to separate the bone and MPPP. These results clearly show that the factors of bone age, type, and the separation device affect the composition of MPPP, as was earlier reported by Goldstrand (1975). Mature bones have been shown to contain larger amounts of fat and greater ash composition than bones from younger pork animals (Field et al., 1974c), resulting in a bone that is harder and less easily broken (Zobrisky, 1969). During the deboning process, greater amounts of ash and crude bone are produced by the hydrostatic friction on older than on younger bones. Pelvic bones are more easily trimmed of lean than back bones, resulting in less MPPP yield and lower amounts of protein in the MPPP.

The influence of age and type of bones on the bone particles produced in MPPP is shown in Figure 15. The bone particles depicted were extracted from the MPPP produced through the top deboning outlet. The bone particles from flat bones appeared to be smaller than those

Table 21. Sums of squares from analysis of variance for composition of MPPP produced with different bone types and ages and outlet types

Source[a]	d.f.	Composition percentage					
		Moisture	Fat	Protein	Ash	Calcium	Bone
Type (T)	1	.49	1.97	29.76**	.216	.037*	.09
Age (A)	1	9.29	6.20	4.52	1.117**	.003	1.38
Outlet (O)	1	4.74	5.24	1.37	.075	.002	1.32*
T x A	1	12.91	60.61**	13.32*	.610*	.025*	.00
T x O	1	.56	.02	5.64*	.004	.005	1.48*
A x O	1	.51	.45	.99	.070	.013	.10
T x A x O	1	1.34	6.03	3.06	.006	.002	.16
Error	8	29.14	37.53	10.08	.615	.047	1.08
Total	15	58.97	118.05	68.74	2.713	.135	5.61

[a]Model was μ(mean) = $T_i + A_j + O_k + TxA_{ij} + TxO_{ik} + AxO_{jk} + TxAxO_{ijk} + E_{ijkl}$, where

T = Effect of bone type (back or pelvic bones), i = 1,2
A = Effect of bone age (mature or young), j = 1,2
O = Effect of outlet type (top or bottom), k = 1,2
TxA, TxO, AxO, TxAxO = Interactions of main effects
E = Error
1 = Observations 1 and 2.

*$p < .05$.

**$p < .01$.

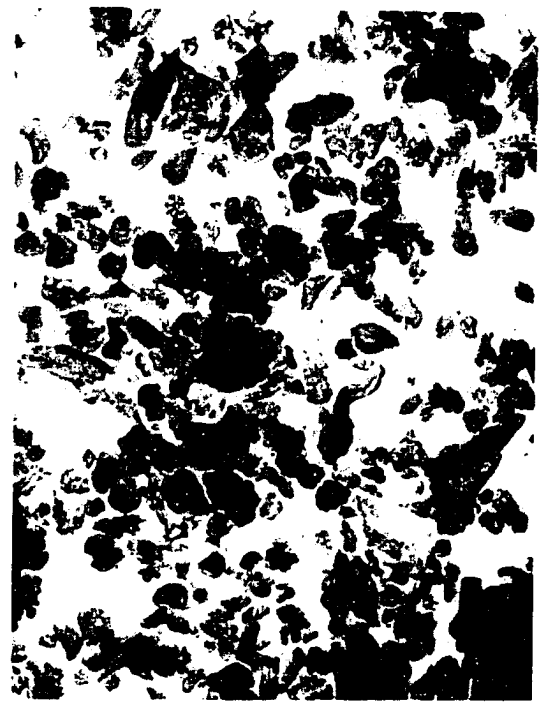
Figure 15. Photomicrographs of bone particles isolated from MPPP produced from frozen back and pelvic mature and young pork bones

A. Young pork back bones, bottom outlet, 30X magnification

B. Mature pork back bones, top outlet, 30X magnification

C. Young pork pelvic bones, bottom outlet, 30X magnification

D. Mature pork pelvic bones, top outlet, 30X magnification




1 mm


A


C

from back bones. The bone particles separated from the mature MPPP (Micrograph B in Figure 15) produced from frozen back bones were much smaller, but more numerous than the particles found in the younger pork bones. The abrasion and friction created during deboning may have caused these harder bones to be more disintegrated. It also appears that these bones were still frozen at the time of deboning since the temperatures recorded were -1.1° and 0°C. The USDA regulations allow frozen storage of bones (Federal Register, 1978), so the prospect of reducing bone particle sizes by deboning frozen bones deserves further study.

Comparisons of fresh and frozen young pork back bones (Table 20) showed no significant differences between moisture, fat, and protein composition of MPPP due to storage temperature or outlet type. However, the amounts of calcium and ash were significantly ($p < .01$) lower in the frozen samples compared to the fresh samples of bones used to produce MPPP (Table 22), but bone percentage was not affected by storage temperature of the bones or outlet type. A significant ($p < .05$) interaction effect of storage temperature by outlet location was observed for the percentage of calcium present in the MPPP samples due to the small range of .06 to .13 percent calcium found in all of the samples tested. The fresh young pork back bones yielded slightly higher amounts of MPPP than the frozen back bones (Table 20). There was also an 11°C temperature rise during deboning of the fresh pork back bones, but only a 4°C temperature rise when the frozen back bones were deboned in the KP hydraulic press. Frozen bones produced smaller bone particles in MPPP than did the fresh bones (Figure 16, Micrographs

Table 22. Sums of squares from analysis of variance for composition of MPPP produced with different outlet types and storage conditions

Source[a]	d.f.	Percent composition					
		Moisture	Fat	Protein	Ash	Calcium	Bone
Storage (S)	1	11.47	11.02	4.64	74.68**	.0039**	.446
Outlet (O)	1	.46	.14	1.00	.32	.000	.002
S x O	1	9.07	18.45	2.45	.33	.0015*	.001
Error	4	22.58	24.32	7.99	.25	.0006	.445
Total	7	43.60	53.93	16.08	75.58	.0060	.894

[a]Model was μ(mean) = $S_i + O_j + SxO_{ij} + E_{ijk}$, where

S = Effect of storage of bones (fresh or frozen), i = 1,2
O = Effect of outlet location (top or bottom), j = 1,2
SxO = Interaction of main effects
E = Error
k = Observations 1 and 2.

*$p < .05$.

**$p < .01$.

Figure 16. Photomicrographs of bone particles isolated from MP(S)P produced from beef and pork bones

A. Fresh young pork back bones, top outlet, 30X magnification

B. Fresh young beef back and neck bones, top outlet, 30X magnification

C. Frozen young pork pelvic bones, top outlet, 30X magnification

D. Frozen young pork back bones, top outlet, 30X magnification


1mm
B


A


C
D

A and B), again suggesting that the freezing process alters the physical or chemical structure of the bones.

The yield from young fresh beef back bones was very low (Table 20), indicating the minimal amount of lean tissue left adhering to the bones from the composition study. Only a 4.5°C temperature rise was recorded during the deboning process, however. Table 23 shows the analysis of variance for composition between MP(S)P produced from young pork and beef back bones. Moisture content was similar between the two species, but the young beef bones produced significantly ($p < .05$) higher fat and lower protein percentages than young pork blades. Ash, calcium, and crude bone percentages remained similar between the two species and outlet locations. Few differences were observed between the species when bone particles were examined under the microscope (Figure 16, Micrographs B and C).

When the compositional traits in phase two were compared by correlation analysis (Table 24), ash was highly correlated with moisture and fat, but not with calcium or bone percentages, as would be expected. Percent crude bone was not highly correlated with calcium due to the small variances of the study, so regression analysis by the stepwise procedure was performed to determine factors which affected the amount of crude bone. Table 25 shows that outlet type had the greatest effect on bone content ($R^2 = .205$). By adding the variables of species and storage conditions of bones, 34 percent of the variation in crude bone was explained. A further addition of bone type and calcium percentage into the prediction equation only explained 2 percent more of the variation in crude bone isolated

Table 23. Sums of squares from analysis of variance for composition of MP(S)P produced from backbones of different species and outlet types

Source[a]	d.f.	Composition percentage					
		Moisture	Fat	Protein	Ash	Calcium	Bone
Species (S)	1	6.46	20.87*	.33	.25	.0004	.058
Outlet (O)	1	4.76	4.21	4.22*	.49	.0000	.113
S x O	1	2.28	6.85	.26	.20	.0013	.066
Error	4	6.72	8.77	1.23	.72	.0035	.237
Total	7	20.22	40.68	6.05	1.66	.0052	.475

[a]Model was μ(mean) = $S_i + O_j + SxO_{ij} + E_{ijk}$, where

S = Effect of species (beef or pork), i = 1,2
O = Effect of outlet location (top or bottom), j = 1,2
SxO = Interaction of main effects
E = Error
k = Observations 1 and 2.

*$p < .05$.

Table 24. Simple correlation coefficients for composition of MP(S)P produced with a hydraulic press deboner

Composition percentage	Composition percentage						
	Moisture	Fat	Protein	Ash	Calcium	Bone	Yield
Moisture	1.00	-.96**	-.04	-.74**	.34	-.04	.04
Fat		1.00	-.14	.70**	-.27	.07	-.17
Protein			1.00	-.11	-.07	-.30	.34
Ash				1.00	-.25	.16	-.08
Calcium					1.00	.16	-.39
Bone						1.00	-.31
Yield							1.00

**p <.01.

Table 25. Coefficients of determination (R^2) for prediction of percentage of crude bone

Variables entered[a]	Equation	R^2	Variables entered[b]	Equation	R^2
Calcium	1	.344	Outlet type	1	.205
Pressure, calcium	2	.357	Outlet type, storage condition	2	.231
Outlet location, calcium, pressure	3	.358	Species, outlet type, storage condition	3	.339
			Calcium percentage, outlet type, storage condition, species	4	.355
			Bone type, outlet type, storage condition, species, calcium percentage	5	.360

[a]Regression equations from phase one with comparisons of different pressures and outlet locations.

[b]Regression equations from phase two with comparisons of bone ages, bone type, storage condition, and species.

from MP(S)P. The regression coefficients and intercepts are not given because the boundaries of application are limited to this study.

The results of this study have shown that many factors affect the composition of mechanically (processed) species product processed through a hydraulic press deboner. The top screen outlet provided smaller bone particle sizes than the concentric ring design of the bottom MP(S)P outlet, although the two outlets were similar in allowing bone particles to enter the MP(S)P during the deboning process. Temperature rises for the bones tested were consistent with those previously reported for mechanical deboning of red meat species. Increased yields were observed when deboning pressures were increased with only minimal changes in MPPP composition except for the crude bone content. Closely trimmed bones were utilized in studying the effects of age, species, bone type, and temperature storage upon MP(S)P characteristics. The small numbers sampled showed freezing of bones may decrease bone particle size, but further study of pre-processing of bones prior to deboning is advised. The MP(S)P from frozen pelvic bones of mature pork and fresh back bones of market-aged beef did not meet the minimum protein and maximum fat standards, respectively, established by the USDA. Other factors studied indicate hydraulic press deboning produces MP(S)P similar to that previously reported in the literature.

PART IV.

CHEMICAL AND NUTRITIONAL CHARACTERISTICS OF MECHANICALLY PROCESSED (SPECIES) PRODUCT PRODUCED FROM BONES OF DIFFERENT TYPES AND AGES

INTRODUCTION

Mechanical deboning to remove the bits of meat left on bones after commercial trimming increases the protein yield, raw material supplies for processed meats, and provides for greater amounts of some vitamins and minerals than is found in hand boned muscle tissue (Field, 1976a). Goldstrand (1975) reported many factors affect the final composition of mechanically processed species product (MP(S)P), including origin and type of bones processed, type and operating characteristics of the deboning machine, the amount of lean removed prior to deboning operations, and pre-treatment of the bones before deboning. Strict compositional limitations on the amounts of fat, protein, and calcium which may be present in MP(S)P have been established by the USDA (Federal Register, 1978), which affect the procedures and bones processed through mechanical deboning machines.

The composition of meat animal bone varies with age and anatomical location, with more mature bones containing greater amounts of fat, ash, and calcium than younger bones (Field et al., 1974c). The amount of calcium present in the bone ash remains constant among bone type or age group when expressed on a dry, fat-free basis (Doyle, 1979), even though ossification and hardening of the bones occurs with increased animal age (Zobrisky, 1969). Field et al. (1974a) reported that the maturity and type of bone affected calcium content of the deboned meat product. Goldstrand (1975) concluded that the composition of bones processed had the greatest influence on the composition of the resulting deboned meat.

Attention has also focused on the protein quality of MP(S)P (Kolbye et al., 1977), but it has been shown that protein quality varies greatly with the amount of lean left on the bones prior to deboning (Chang and Field, 1977). The USDA provides that MP(S)P must provide a protein efficiency ratio (PER) of 2.5 or greater or contain 33 percent of the amino acid residues as essential amino acids (Federal Register, 1978). Field et al. (1979) recently found that MP(S)P from beef bones did not meet the PER requirement, while pork neck bones did produce MP(S)P with satisfactory PER values, and they established a multiple regression equation to predict the PER values from amino acid composition.

A majority of the previous studies has produced MP(S)P with a rotary type of deboner, but many types of deboning machines are available to produce MP(S)P (Anonymous, 1976). The present study was conducted to determine the nutritional and chemical composition of MP(S)P which was produced from bones of different species, anatomical locations, and physiological ages. Two types of deboning machines, a hydraulic press deboner and a continuous rotary deboner, were used to produce MP(S)P from commercial sources of trimmed bones.

EXPERIMENTAL

The bones processed through the deboning machines were obtained from commercial packing companies after regular trimming of the lean from the bones was completed. Beef back bones and pork back bones were transported fresh from the commercial boning lines 160 km to the meat laboratory and fresh pork blade bones were transported 72 km to the laboratory. All bones were stored in a 2°C cooler overnight and processed the following day through a Meat Removal System, a hydraulic press deboner loaned by the Kartridg-Pak Company, Davenport, Iowa. Both top and bottom straining outlets of the KP press deboner consisted of three concentric extrusion rings which strained the muscle tissue from the bones. Maximum tolerance between the extrusion rings and receiver assembly was .23 mm at the separating surface with a maximum distance of .69 mm between the sides of the rings and stationary assembly where the MP(S)P exited after removal from the bones. A Yieldmaster rotary deboner (The Kartridg-Pak Company, Davenport, Iowa) utilized a variable speed Reeves motor to drive the auger carrying meat tissue and bone to the separating screen with .45 mm diameter holes.

Beef bones from the boned wholesale rib consisted of thoracic vertebrae and costae (ribs) and were separated into three age groups based on physiological bone maturity and ossification and carcass quality grade. Young beef back bones were less than 30 months of age, mature beef back bones were C, D, and E maturity from Commercial cow carcasses, and utility beef back bones were both young and mature

bones from Standard and Utility grade carcasses. Pork blade (scapula) bones were separated into two groups based on live animal weights. Mature blade bones were from sows of 205 kg or greater weight, and young blade bones were from market weight hogs of less than 127 kg. Mature pork back bones (thoracic, lumbar, and sacral vertebrae) were obtained from the boned loins of the sows weighing 205 kg or greater. All bones were ground through a Weiler grinder with a 2.54 cm plate and processed in repetitive batches of 1.9 kg through the KP press deboner operated at 24,115 kilopascals. The MP(S)P was then chilled to 4°C, sampled, and then placed into the hopper of a Ve-Mag vacuum stuffer and pumped into the Yieldmaster rotary deboner at a continuous pressure of 83 kilopascals. The Yieldmaster rotary deboner was operated at varying speeds of 300, 600, 900, 1200, and 1400 revolutions per minute (rpm) for production runs with the different MP(S)P. After chilling to 4°C, samples were taken for analysis and remaining MP(S)P was frozen and stored at -20°C.

Yields of MP(S)P from the KP press were calculated by difference after weighing the ground bones prior to deboning and the resulting bone residue after deboning. Yields of MP(S)P from the Yieldmaster deboner were calculated by weighing the MP(S)P and bone residue after deboning. Temperatures of the ground bones, MP(S)P, and bone residues were recorded immediately prior to or following the deboning operations. AOAC (1975) procedures were followed for determination of moisture, crude fat, Kjeldahl protein, and ash in the MP(S)P and bone residue samples. Calcium content was measured on acid-ashed samples by the procedure of Ewan et al. (1979) with a Varian Techtron AA-5 atomic

absorption spectrophotometer. Percentage of crude bone was obtained by extending the procedure of Hill and Hites (1968) to a 30 hour papain digestion of samples and then separating the crude bone by acetone: carbon tetrachloride flotation. Bone particles were mounted onto slides with glycerol gelatin and photomicrographs (8.26 x 10.8 cm) taken with a Polaroid camera mounted on a Balplan (Bausch and Lomb) phase contrast microscope.

Samples of MP(S)P from the young and mature beef back and pork blade bones were freeze-dried and then extracted with hexane for 24 hours to determine the nutritional protein quality. The freeze-dried, extracted MP(S)P samples were analyzed for amino acid composition on a Durrum D-400 amino acid analyzer by the Biochemistry Department after HCl hydrolysis and performic acid oxidation. The results of one oxidized sample and duplicate hydrolyzed samples were combined and presented as the number of amino acid residues per 100 amino acid residues in the protein. Moisture, crude fat, protein, and ash were measured by AOAC (1975) procedures on the freeze-dried, extracted samples and are shown in Table A.13. The amount of calcium, magnesium, sodium, potassium, and iron was determined by the procedure of Ewan et al. (1979) by atomic absorption spectroscopy (Varian Techtron AA-5).

General procedures of the AOAC (1975) were followed to determine the protein efficiency ratio (PER) and relative PER ratios of diets containing MP(S)P and casein. Ninety male weanling Sprague-Dawley albino rats 21 days of age were obtained (SASCO, Omaha, Nebraska), weighed, and ranked according to weight. The rats were housed in three tiers of the two 60-cage racks. The heaviest 18 rats were

randomly assigned cages in the top row of the racks, the second heaviest group of 18 rats randomly assigned to the second row, and so forth, until the lightest weight group was randomly assigned to the bottom row of cages. Duplicate diets of the eight sample MP(S)P treatments (KP and Yieldmaster deboners, beef and pork species, and mature and young bones) and a casein control diet were randomly assigned to the rats in each of the five rows of cages. Each diet contained 10 percent protein, 5 percent fat, 5 percent vitamin and mineral premixes, and the remainder of the diet was sucrose (Table 26). The rats were fed for 28 days with body weight and the amount of feed consumed determined every fifth day. Protein efficiency ratios were calculated as PER = body weight gain/amount of protein consumed and relative PER ratios calculated as PER of test diet/PER of casein diet x 100. Feed and water (.275 percent tetracycline hydrochloride) were provided ad libitum to the individually housed rats.

Statistical comparisons of data were performed using the SAS analysis of variance procedure (Barr et al., 1976), Duncan's multiple range tests (Duncan, 1955), and regression analyses (Draper and Smith, 1966).

Table 26. Diet formulation for protein efficiency ratio determination

Ingredient	Percent of diet
Protein source[a]	12.0
Sucrose	77.9
Vitamin premix[b]	1.0
Riboflavin premix[c]	.5
Vitamin B_6 premix[d]	.5
70% choline chloride	.1
Mineral premix[e]	3.0
Corn oil	5.0

[a]Average composition of freeze-dried, extracted MP(S)P was 3.94% moisture, .26% fat, 83.68% protein, and 10.02% ash (2.94% Ca, 22% Mg, 5.96% Na, 1.42% K, and .034% Fe).

[b]Vitamin premix was composed of 97.58% sucrose, .014% retinyl acetate, .80% vitamin D_3, 1.0% vitamin E acetate, .1% menidione, .01% folic acid, .2% niacin, .16% dl Ca pantothenate, .04% thiamin, and .1% vitamin B_{12}.

[c]Riboflavin premix was composed of 99.94% sucrose and .06% riboflavin.

[d]Vitamin B_6 premix was composed of 99.88% sucrose and .12% B_6.

[e]Mineral premix was composed of 67.21% Ca HPO_4, 6.67% K_2HPO_4, 6.67% K_2SO_4, 11.47% KCl, 4.33% NaCl, 2.33% MgO, .08% $ZnCO_3$, .583% $FeSO_4 \cdot 7H_2O$, .043% $CuSO_4$, .533% $MnSO_4 \cdot H_2O$, .003% KIO_3, .007% $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$, .013% $CoCl_2 \cdot 6H_2O$, .007% NaF, .003% $K_2Cr_2O_7$, .04% $NiCl_2 \cdot 6H_2O$, and .013% $SnCl_2 \cdot 2H_2O$.

RESULTS AND DISCUSSION

Temperatures recorded during deboning and yields from the two deboners and different bones are shown in Table 27. Temperature increases were less than 10°C with the Kartridg-Pak press when beef and pork bones were deboned and when pork bones were deboned with the KP press. However, beef back bones caused temperature rises during continuous deboning by the Yieldmaster rotary deboner to vary from 9.5 to 19.5°C. Field et al. (1975) reported temperature rises of 6 to 18°C when a Beehive rotary deboner was used for pork bones and choice beef bones, but a range of 13 to 30°C temperature increase when cow beef bones were processed. In the present study, yields of mechanically processed beef product (MPBP) were much lower than yields of mechanically processed pork product (MPPP) from the KP press deboner. Younger bones gave slightly higher yields than more mature bones, both with beef and pork species. Because the beef back bones also had the ribs attached, which are closely trimmed under commercial conditions, yields were lower than for the pork back bones which included only the vertebral column. Field et al. (1975) obtained higher yields from neck, rib, and short loin beef bones and sow loin bones, but lower yields of MPPP from picnic and Boston butt bones with a rotary deboner than were obtained with the KP press in the present study. Goldstrand (1975) reported comparable yields for beef loin rack and chuck rib bones and pork back and blade bones to those reported here. Because the MP(S)P was processed through the Yield-master rotary deboner after the bones were run through the KP press

Table 27. Mean values[1] and standard errors of means[2] for yield of MP(S)P produced by different deboners from bones of different types, ages, and species

			KP press deboner			Yieldmaster rotary deboner				
Species	Bone age	Bone type	Bone temp. (°C)	MP(S)P temp. (°C)	Percent yield	rpm	Ring	Bone temp. (°C)	MP(S)P temp. (°C)	Percent yield
Beef	Mature	Backs	4.4	12.2	18.95^{h}	1200	2	8.3	18.3	79.04^{bcd}
	Young	Backs	3.3	12.2	24.50^{h}	600	2	7.2	18.3	93.27^{ab}
						900	2	7.2	18.3	94.17^{ab}
						1200	2	7.2	26.7	86.00^{abcd}
	Utility	Backs	3.3	12.7	18.84^{h}	900	1	6.1	15.6	86.96^{abcd}
s.e.m.					3.59					4.79
Pork	Mature	Backs	5.5	11.1	44.63^{g}	300	2	6.1	18.3	92.00^{abc}
						600	2	8.3	18.3	95.69^{a}
						900	1	1.9	10.0	51.16^{fg}
						900	2	4.4	13.9	88.99^{abc}
						1200	1	2.2	8.3	76.10^{de}
						1200	2	8.3	18.3	90.27^{abc}
						1400	1	4.4	8.9	61.49^{ef}
	Mature	Blades	2.2	11.1	37.72^{g}	900	1	6.1	7.2	92.04^{abc}
						1200	1	1.1	8.3	76.43^{cd}
	Young	Blades	2.2	11.7	38.73^{g}	900	2	13.3	20.0	95.97^{a}
s.e.m.					4.01					4.35

[1]Means with the same superscript letter are not significantly different ($p < .05$).

[2]Standard errors of means are averages for each deboning machine and species.

the yields shown in Table 27 are valid for comparative purposes only. Yields varied with speed of deboning, with higher speeds resulting in generally greater yields. It should be noted that compression ring number one was a desinewing head, while compression ring number two was a normal deboning head. Yields were higher with the normal compression ring as compared to the desinewing ring at similar operating speeds. Overall, operating speeds of 600 and 900 rpm gave the highest yields of MP(S)P.

Proximate analysis values showed small differences for moisture, fat, and protein content of MP(S)P between the KP press and Yieldmaster deboners (Table 28). It may be observed that the MPBP from young beef bones met both the fat and protein requirements of less than 30 percent and greater than 14 percent, respectively, established by the USDA, and the MPPP from blade bones was less than 30 percent fat, but all other samples were far from compliance. It was stated by Goldstrand (1975) that the sole alternative to bring fat and protein levels of MP(S)P from trimmed bones into compliance was to increase the lean content of bones by reducing the amount of lean removed during hand-boning operations. The data in Table 28 show that most of the material separated by the Yieldmaster from the MP(S)P produced by the press was bone material. There was a decrease in ash, crude bone, and calcium content of MP(S)P after deboning the MP(S)P through the Yieldmaster deboner. All samples were below the .75 percent calcium standard with the exception of MPBP produced from mature beef back bones with the KP press deboner, which was .76 percent calcium. Other researchers (Field et al., 1975, and Goldstrand, 1975) had

Table 28. Mean values[1] and standard errors of means[2] for composition of MP(S)P produced by different deboners from bones of different types, ages, and species

Species	Bone age	Bone type	Percent composition: Moisture KP[3]	Moisture YM[4]	Fat KP	Fat YM
Beef	Mature	Backs	47.42^{de}	48.33^{d}	37.93^{a}	38.59^{a}
			(1.02)	(1.02)	(1.05)	(1.05)
Beef	Young	Backs	53.93^{bc}	53.11^{c}	29.96^{bc}	32.11^{b}
			(1.02)	(1.02)	(1.05)	(1.05)
Beef	Utility	Backs	44.80^{e}	45.79^{de}	39.57^{a}	42.05^{a}
			(1.24)	(1.76)	(1.29)	(1.82)
Pork	Mature	Backs	53.68^{c}	53.72^{c}	31.32^{bc}	31.71^{b}
			(1.02)	(.24)	(1.05)	(.50)
Pork	Mature	Blades	57.06^{b}	54.88^{bc}	28.31^{c}	32.08^{b}
			(1.24)	(1.02)	(1.29)	(1.05)
Pork	Young	Blades	63.26^{a}	63.55^{a}	21.11^{d}	19.70^{d}
			(1.76)	(1.76)	(1.82)	(1.82)

[1]Means for each component with the same superscript letter are not significantly different ($p < .05$).

[2]Standard errors of means are in parentheses below each mean.

[3]KP = KP Meat Removal System press.

[4]YM = Yieldmaster rotary deboner.

Protein		Ash		Crude bone		Calcium	
KP	YM	KP	YM	KP	YM	KP	YM
12.17^{b}	11.36^{b}	2.05^{ab}	1.38^{cd}	1.19^{b}	$.29^{d}$	$.76^{a}$	$.38^{bc}$
(.49)	(.49)	(.11)	(.11)	(.09)	(.09)	(.07)	(.07)
14.05^{a}	10.91^{b}	1.90^{b}	1.57^{c}	1.06^{b}	$.24^{d}$	.61	$.23^{c}$
(.49)	(.49)	(.11)	(.11)	(.09)	(.09)	(.07)	(.07)
13.01^{ab}	11.61^{b}	2.31^{a}	1.45^{dc}	1.60^{a}	$.21^{d}$	$.44^{bc}$	$.29^{c}$
(.61)	(.86)	(.14)	(.19)	(.12)	(.16)	(.09)	(.13)
11.88^{b}	12.05^{b}	2.08^{ab}	1.36^{cd}	$.62^{c}$	$.20^{d}$	$.50^{b}$	$.30^{c}$
(.49)	(.24)	(.11)	(.05)	(.09)	(.05)	(.07)	(.04)
12.61^{ab}	11.66^{b}	1.38^{cd}	1.16^{d}	$.44^{cd}$	$.20^{d}$	$.18^{c}$	$.22^{c}$
(.61)	(.49)	(.14)	(.11)	(.12)	(.09)	(.10)	(.07)
11.66^{b}	13.06^{ab}	1.48^{cd}	1.30^{cd}	$.52^{cd}$	$.17^{d}$	$.41^{bc}$	$.20^{c}$
(.86)	(.86)	(.19)	(.19)	(.16)	(.16)	(.13)	(.13)

reported similar calcium levels in MP(S)P from beef back and pork blade and back bones processed by deboning.

Simple correlation coefficients were determined for composition of the MP(S)P from the different bone types and two deboners (Table 29). Yield of MP(S)P was significantly correlated ($p < .01$) with the amount of protein, ash, crude bone, and calcium. Protein was related to the amount of fat ($r = -.24$), but not to the moisture content of the MP(S)P. Protein composition was also highly related to the ash, crude bone, and calcium contents. A very high correlation ($r = .80$) was discovered between ash and crude bone, but the relationships of calcium to ash and crude bone were lower ($r = .62$ and $r = .61$, respectively). Field (1976a concluded scapula (blade) bones are less desirable than vertebrae and rib bones for deboning because more of the bone marrow was fat. It would seem that the fat content would be related to yield and also to ash, crude bone, and calcium if bone marrow fat were a contributor to MP(S)P content. This relationship was not seen in the present study, although Field *et al.* (1975) reported that bone marrow, lean, and some bone particles accounted for the higher yields of mechanically deboned meat than was possible by hand removal of meat from bones.

The USDA states that the percentage of powdered bone shall be determined by multiplying the calcium content of MP(S)P by the factor of 4. Regression equations were developed for the present study to determine if crude bone, calcium, or yield of MP(S)P could be predicted. As Table 30 shows, yield explained 64.6 percent of the variation in crude bone content of MP(S)P. Addition of ash content, bone age, specie, and protein percentage as variables into the stepwise regression

Table 29. Simple correlation coefficients for composition of MP(S)P produced by different deboners from bones of different types, ages, and species

	Percent composition						
Component	Yield	Moisture	Fat	Protein	Ash	Crude bone	Calcium
Yield	1.00	.28*	-.17	-.36**	-.65**	-.80**	-.64**
Moisture		1.00	-.97**	.15	-.31**	-.33**	-.25*
Fat			1.00	-.24*	.16	.18	.15
Protein				1.00	.32**	.38**	.27*
Ash					1.00	.80**	.62**
Crude bone						1.00	.61**
Calcium							1.00

*$p < .05$.

**$p < .01$.

program allowed 81.3 percent of the variation in crude bone content to be explained. Calcium content was not included as a major predictor of crude bone content in the regression procedure, suggesting that measurement of calcium to estimate bone content is inaccurate, even though bone ash contains 36 percent calcium (Doyle, 1979). In the present study, the simple correlation coefficient of .61 between calcium and crude bone would explain 37 percent of the variation in crude bone which is accounted for by calcium content. In Table 30, yield of MP(S)P accounted for 41 percent of the variation in calcium percentage present in MP(S)P. Even after the variables of ash percentage, deboner type, bone age, and specie of bones were added to the regression equation, only 58 percent of the variation in calcium content was explained. The amount of crude bone did not enter the regression analysis for

Table 30. Stepwise regression equations for prediction of percentage of crude bone, calcium, and yield

Equation for crude bone (%)	Variable entered	b value	R^2
1	Intercept	1.324	.646
	Yield (%)	-.013	
2	Intercept	.127	.782
	Yield (%)	-.008	
	Ash (%)	.551	
3	Intercept	.437	.804
	Yield	-.007	
	Ash (%)	.496	
	Specie[a]	-.158	
4	Intercept	.295	.809
	Yield	-.008	
	Ash (%)	.479	
	Specie[a]	-.112	
	Bone age[b]	.071	
5	Intercept	.067	.813
	Yield (%)	-.007	
	Ash (%)	.468	
	Specie[a]	-.123	
	Bone age[b]	.064	
	Protein (%)	.021	

[a]Specie values = 1 for beef, 2 for pork.

[b]Bone age values = 1 for mature, 2 for young, 3 for utility.

[c]Deboner values = 1 for K-P press, 2 for Yieldmaster.

[d]RPM = revolutions per minute.

Equation for calcium (%)	Variable entered	b value	R^2	Equation for yield (%)	Variable entered	b value	R^2
1	Intercept	.697	.409	1	Intercept	-25.15	.800
	Yield (%)	-.005			Deboner[c]	54.59	
2	Intercept	.269	.483	2	Intercept	-.60	.845
	Yield (%)	-.003			Deboner[c]	46.86	
	Ash (%)	.197			Calcium (%)	-31.73	
3	Intercept	.033	.527	3	Intercept	-24.43	.871
	Yield (%)	-.006			Deboner[c]	68.42	
	Ash (%)	.233			Calcium (%)	-27.44	
	Deboner[c]				RPM[d]	-.02	
4	Intercept	.092	.558	4	Intercept	-67.16	.886
	Yield (%)	-.006			Deboner[c]	67.18	
	Ash (%)	.263			Calcium (%)	-23.45	
	Deboner[c]	.221			RPM[d]	-.02	
	Bone age[b]	-.069			Moisture (%)	-23.45	
5	Intercept	.317	.579	5	Intercept	-40.72	.905
	Yield (%)	-.006			Deboner[c]	69.53	
	Ash	.242			Calcium (%)	-18.40	
	Deboner[c]	.189			RPM[d]	-2.43	
	Bone age[b]	-.101			Moisture (%)	1.01	
	Specie[1]	-.086			Protein (%)	-3.34	

percentage of calcium by stepwise procedures. Eighty percent of the variation in MP(S)P yield was explained by the type of deboning machine utilized, which was expected as only two types of deboners were used and the variations in yields were limited. Over 90 percent of the yield variation was explained when the variables of calcium, moisture, and protein percentages, and speed of the Yieldmaster deboner were added in the stepwise regression procedure.

Photomicrographs of bone particles isolated from MP(S)P were taken to determine differences in relative sizes or shapes by deboning procedures or bone types. Figure 17 shows bone particles produced by the Yieldmaster rotary deboner. The black line on Micrograph C indicates a distance of 1 mm. The mature pork blade bones seemed to fragment more during the deboning process as more numerous, smaller particles were seen than for other bone types. However, less crude bone was isolated from the MP(S)P from these bones than from the other types of bones processed in the Yieldmaster deboner (Table 28). All of the bone particles were less than the .85 mm maximum size, but estimates of the number of particles less than .5 mm (Federal Register, 1978) were not made. Bone particles isolated from the MP(S)P produced by the Kartridg-Pak Meat Removal System press are shown in Figure 18. Young bones were fragmented more than older bones, although the percentage of crude bone isolated from samples was not different. Several of the bone particles were longer than 1 mm, supporting the conclusions in Part III that long, splintered bone particles are forced into MP(S)P by the concentric ring design of the KP press. No large differences in bone shape were noted when beef bone particles from the

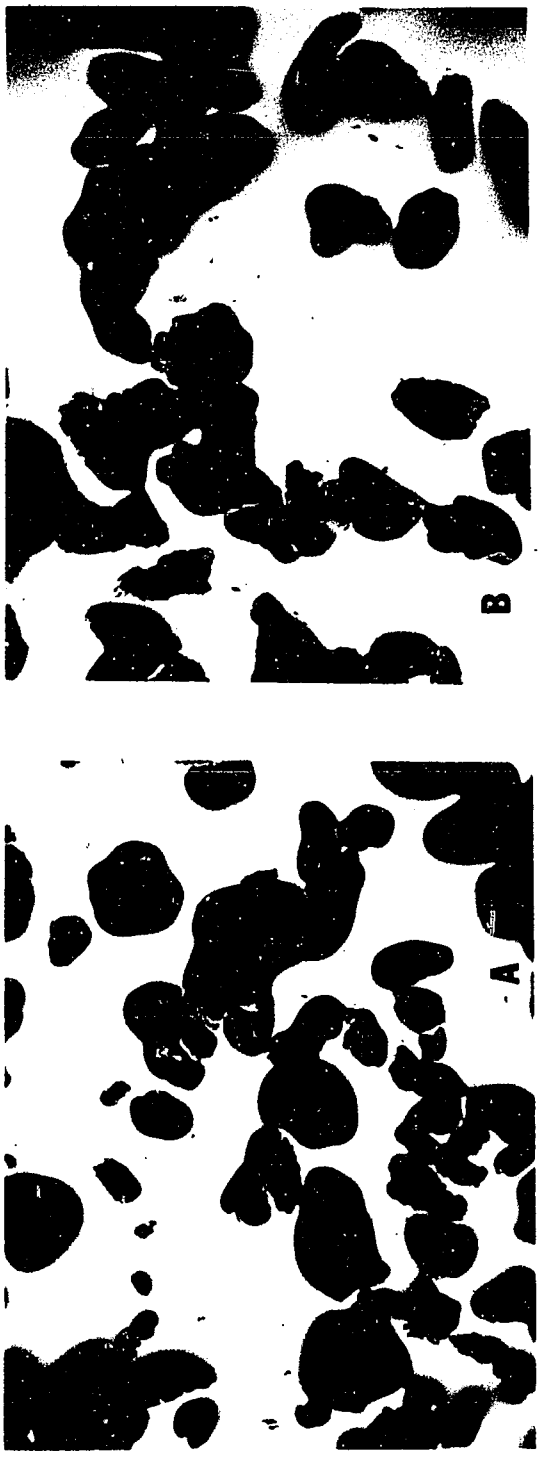
Figure 17. Photomicrographs of bone particles isolated from MP(S)P produced by a Yieldmaster rotary deboner

A. Mature pork blade bones, 30X magnification

B. Mature beef back bones, 30X magnification

C. Young pork blade bones, 30X magnification

D. Young beef back bones, 30X magnification


B
A

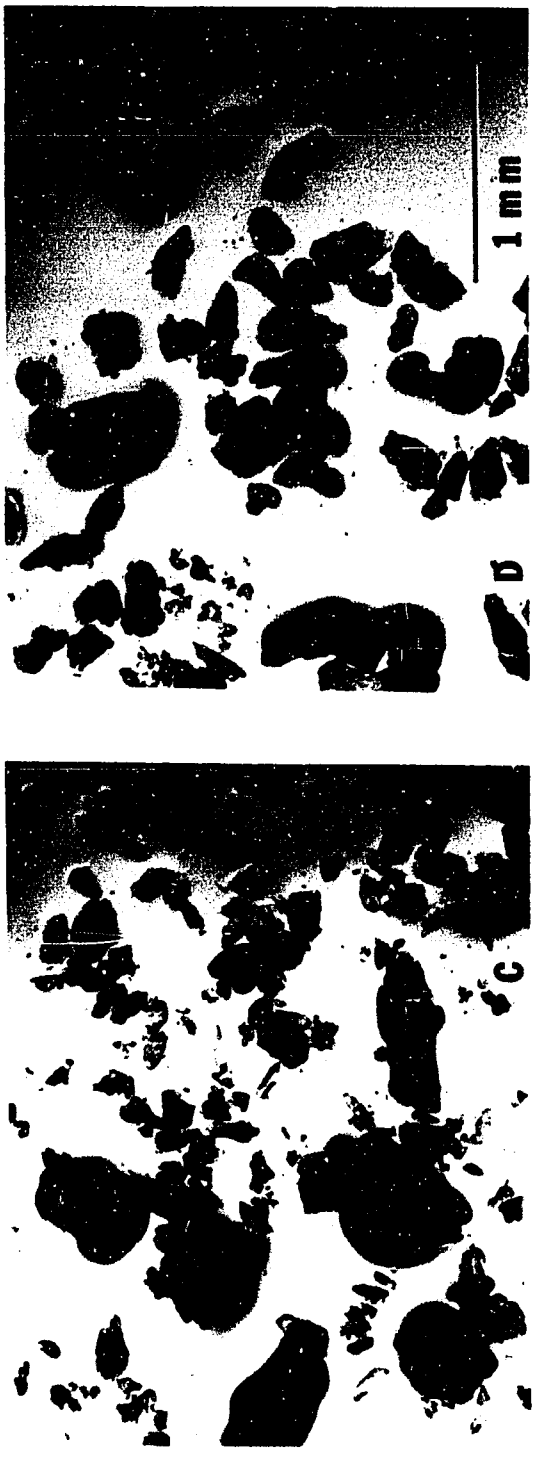

1 mm
D
C

Figure 18. Photomicrographs of bone particles isolated from MP(S)P produced by a Kartridg-Pak press deboner

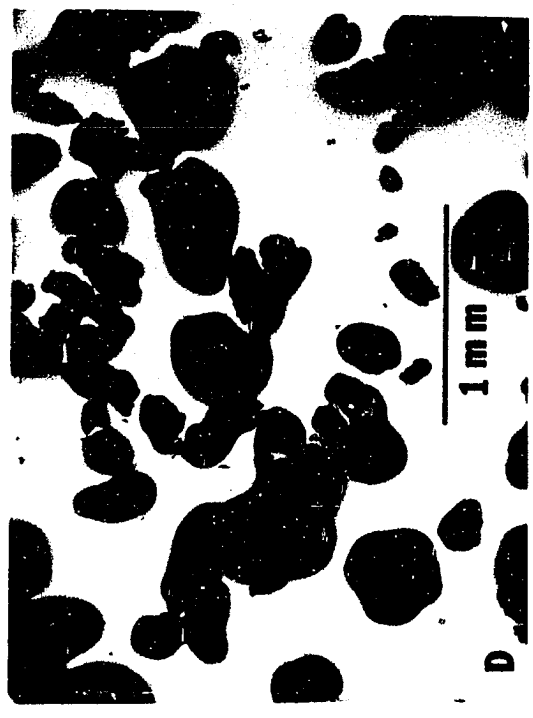
A. Mature pork blade bones, 30X magnification

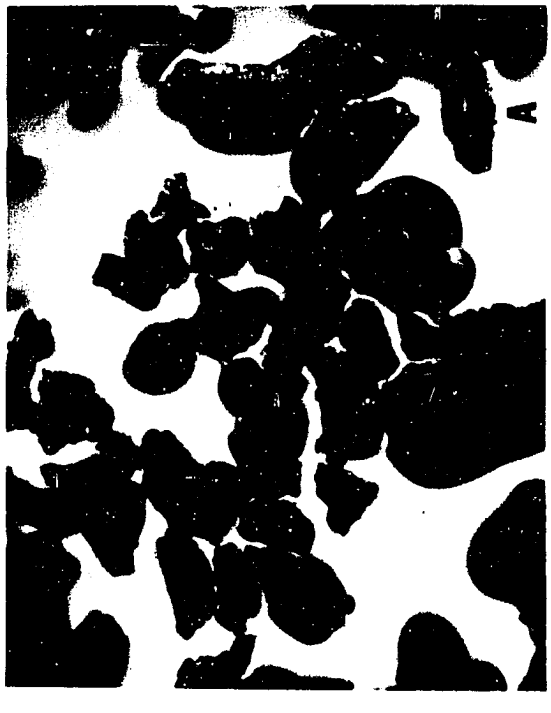
B. Mature beef back bones, 30X magnification

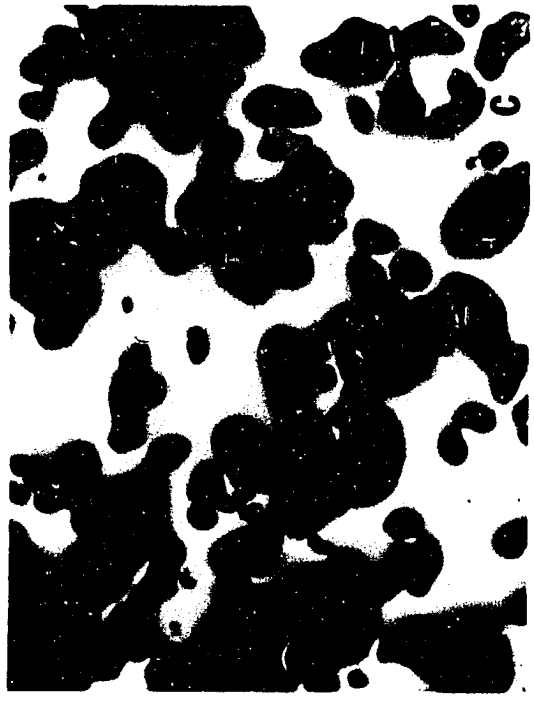
C. Young pork blade bones, 30X magnification

D. Young beef back bones, 30X magnification


B


1mm
D


A


C

KP press and Yieldmaster were compared (Figure 19), although bone particles in MPBP from the Yieldmaster (Micrographs C and D) were more rounded and smooth compared to those produced by the KP press (Micrographs A and B). Great differences were observed when bone particles from pork blade bones were compared between the KP press and Yieldmaster rotary machines (Figure 20). Photomicrograph A depicts bone particles from mature pork blade bones produced by the KP press. The particles are much larger than those produced from mature blade bones by the Yieldmaster, and they have a more splintered, elongated appearance. The other three micrographs show isolations of bone particles which would appear to meet the size limitations imposed by the USDA (Federal Register, 1978). It may be seen in Figure 21 that the Yieldmaster is of benefit in removing the larger bone particles produced by the KP press. Micrographs A and B are bone particles isolated from mature pork and beef bones, respectively, present in the bone residue separated as waste by the Yieldmaster rotary mechanical deboner. The bone residue particles for young pork and beef are shown in Micrographs C and D, respectively. Relative sizes and shapes of all four bone particle types are similar, sizes being much larger than .85 mm and the shapes being elongated but smooth due to the friction and agitation of the continuous Yieldmaster deboner. Bone particle shapes in all micrographs appeared very similar to those observed by Field et al. (1977) and Froning (1979) on bone particles isolated after mechanical deboning.

Amino acid analysis (Table 31) showed few differences among the treatment groups and casein, but all treatment MP(S)P samples contained

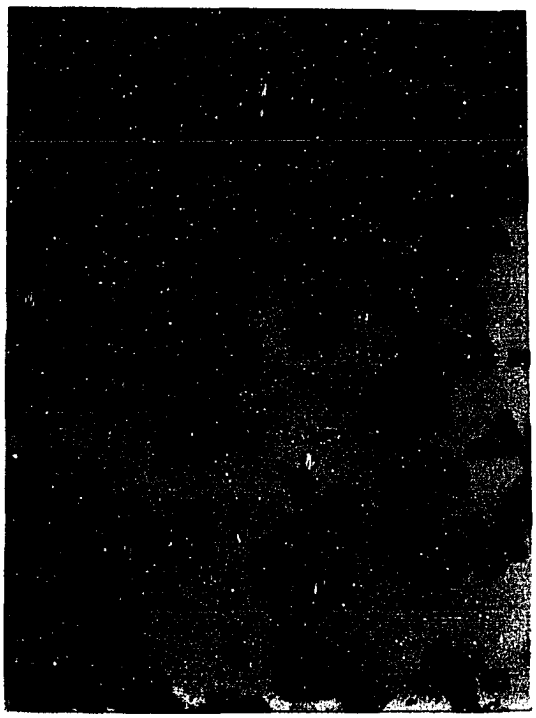
Figure 19. Photomicrographs of bone particles isolated from MPBP produced by the Yieldmaster and KP deboners

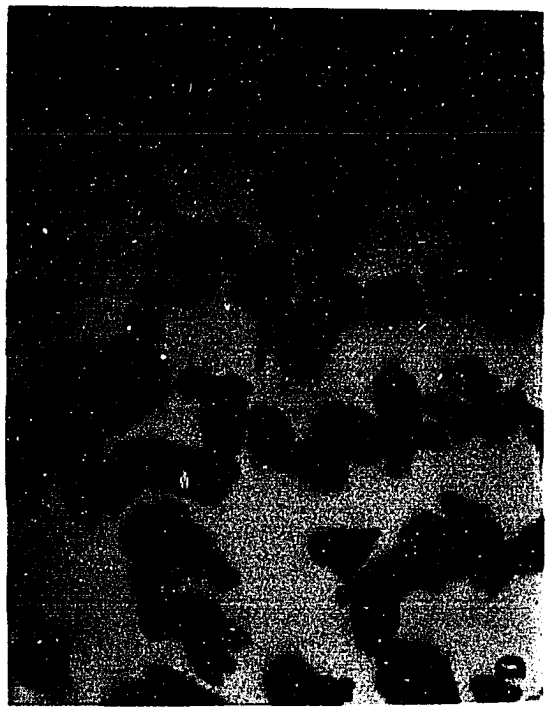
A. KP press deboner, young beef back bones, 30X magnification

B. KP press deboner, mature beef back bones, 30X magnification

C. Yieldmaster rotary deboner, young beef back bones, 30X magnification

D. Yieldmaster rotary deboner, mature beef back bones, 30X magnification





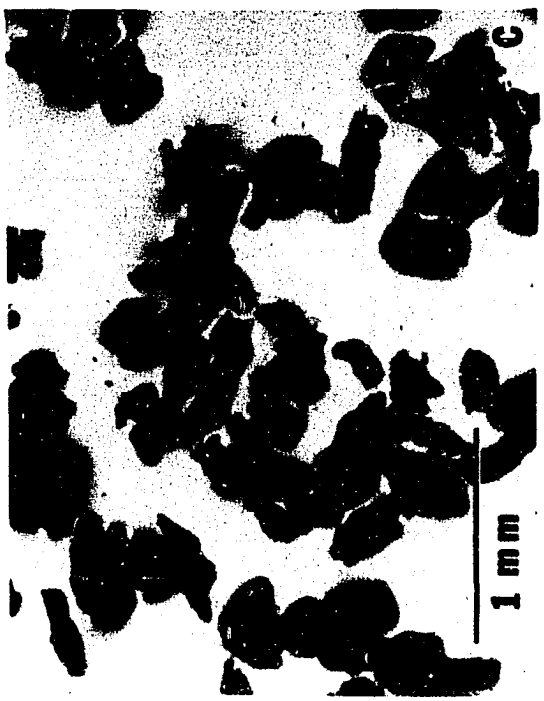

1 mm

Figure 20. Photomicrographs of bone particles isolated from MPPP produced by the Yieldmaster and KP deboners

A. KP press deboner, mature pork blade bones, 30X magnification

B. KP press deboner, young pork blade bones, 30X magnification

C. Yieldmaster rotary deboner, mature pork blade bones, 30X magnification

D. Yieldmaster rotary deboner, young pork blade bones, 30X magnification


B


1 mm


C

Figure 21. Photomicrographs of bone particles isolated from the bone residue produced by the Yieldmaster rotary deboner

A. Mature pork blade bones, 30X magnification

B. Mature beef back bones, 30X magnification

C. Young pork blade bones, 30X magnification

D. Young beef blade bones, 30X magnification

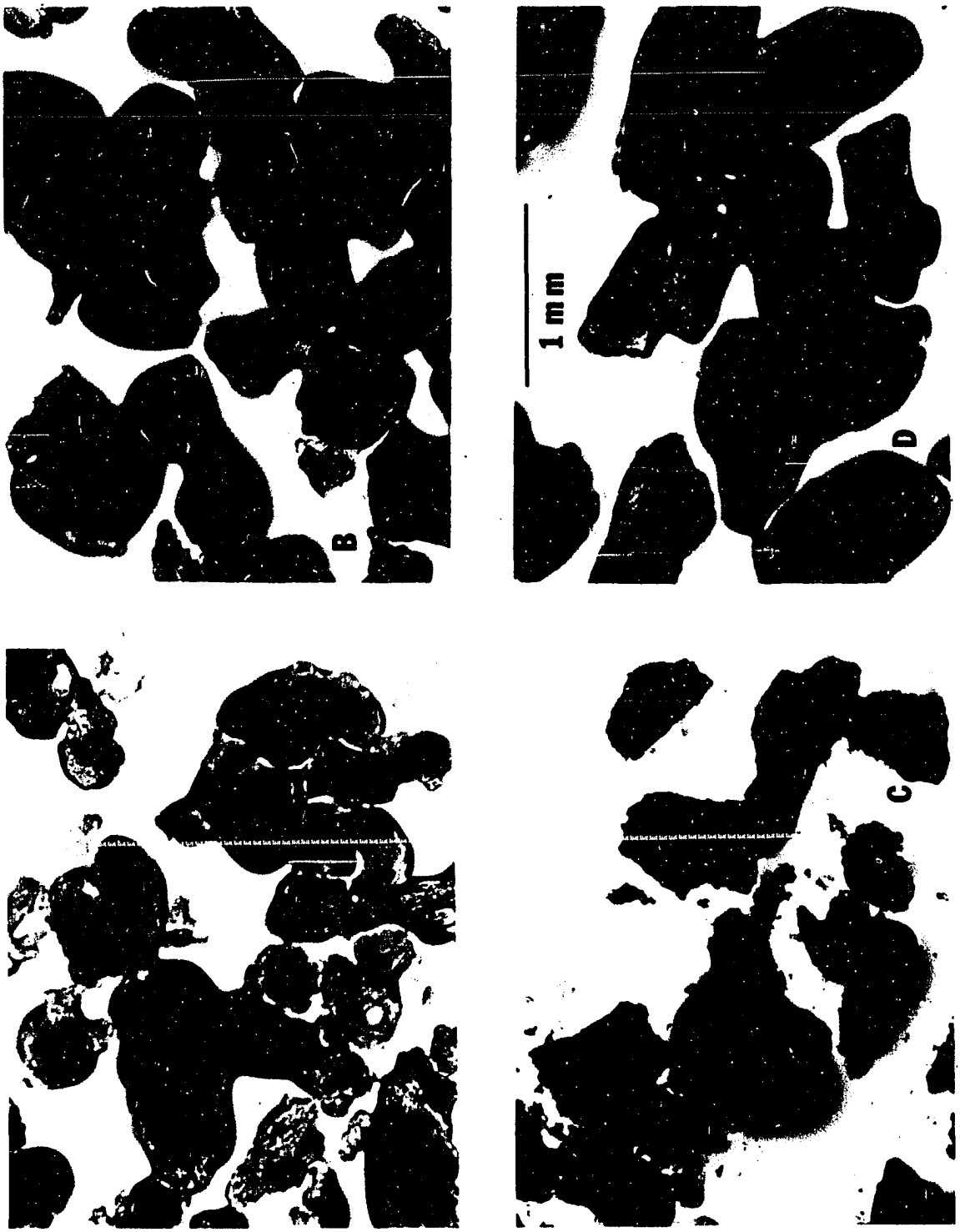

B
1 mm
D
C

Table 31. Mean values[a] for amino acid composition[b] of freeze-dried, extracted MP(S)P and casein

Amino acid	Casein	Composition of MP(S)P samples							
		KP press deboner				Yieldmaster deboner			
		Beef		Pork		Beef		Pork	
		Mature	Young	Mature	Young	Mature	Young	Mature	Young
CYS	.50	1.74	1.28	1.23	1.44	1.64	1.35	1.28	1.31
ASP	6.60	8.91	8.94	9.12	8.25	7.15	7.87	8.97	9.20
MET[c]	2.82	2.41	2.24	2.43	2.69	2.14	2.41	2.54	2.45
THR	4.55	5.19	5.22	4.94	4.82	4.69	4.88	4.87	5.22
SER	6.86	5.78	5.74	5.27	5.11	4.98	5.24	5.25	5.50
GLU	17.12	11.43	11.34	12.58	12.24	10.57	11.44	12.55	11.96
PRO	10.86	4.88	4.87	4.76	4.99	5.93	5.34	4.64	4.92
GLY	3.60	9.38	10.10	9.42	8.96	12.44	11.16	9.32	8.92
ALA	4.74	10.03	10.14	8.99	9.02	10.98	10.07	9.10	9.24
VAL	6.82	6.41	5.91	6.13	6.58	7.08	6.27	5.70	6.25
ILE	5.10	3.85	3.93	4.37	4.61	3.85	4.11	4.59	4.35
LEU	8.94	8.48	8.82	8.42	8.69	8.34	8.41	8.54	8.43
TYR	4.47	2.61	2.64	2.89	2.89	2.32	2.37	2.90	2.94
PHE	4.55	3.82	3.84	3.87	3.87	3.61	3.76	3.76	3.92
LYS	6.56	7.03	7.34	7.26	7.47	6.93	7.12	7.39	7.32
HIS	2.81	2.79	2.89	2.79	3.01	2.58	2.97	2.93	3.04
ARG	3.11	5.28	4.80	5.54	5.37	4.76	5.23	5.68	5.02
eaa[d]	39.34	37.19	37.30	37.42	38.73	36.64	36.96	37.39	37.94

[a]Means are averages of three duplicate samples (one oxidized and two hydrolyzed).

[b]Expressed as amino acid residues/100 amino acid residues in the protein.

[c]Derived from oxidized samples as methionine sulfone.

[d]Essential amino acid residues/100 amino acid residues in the protein where the eaa are ILE, LEU, LYS, MET, PHE, THR, and VAL.

greater than the 33 percent essential amino acids of total amino acids as required by USDA (Federal Register, 1978). The casein protein contained less cysteine, aspartic acid, glycine, alanine, and arginine as amino acid residues, but more glutamic acid, proline, tyrosine, and phenylalanine than the MP(S)P protein samples. The casein diet was also slightly higher in percentage of essential amino acids than the MP(S)P samples. The amino acid analyses in this study showed less histidine, isoleucine, lysine, phenylalanine, and tyrosine amino acid residues for MP(S)P than Happich et al. (1975) reported for lean beef, and higher threonine, serine, glycine, alanine, methionine, leucine, and lysine amino acid percentages than reported by Chang and Field (1977) and Field et al. (1979) for different types of MP(S)P. In the previous studies, Happich et al. (1975) reported a PER of 2.85 for lean beef and PER of 2.50 for a casein control. Chang and Field (1977) found that MP(S)P diets fed to rats at a 9 percent protein level resulted in a range of PER values from -.55 to 2.69 compared to a PER of 3.63 for rats fed a lactalbumin protein diet. A PER of 2.97 for casein and PER ranges of 1.44 to 2.91 for different sources of MP(S)P in diets were reported by Field et al. (1979). Table 32 is a summary of the protein efficiency ratio trials conducted by feeding groups of ten rats each of the formulation diets containing 10 percent protein. Because the rats were sorted by weight and then randomly assigned to cages, no significant differences in initial group weights were observed among diet groups. There were large differences in the amount of weight gained, protein consumed, PER, and relative PER among the different diet groups, however. Rats which were fed the MPBP diets

Table 32. Mean values[1] and standard errors of means[2] for growth rates of rats fed MP(S)P and casein diets

Diet group	Initial weight (g)	Total weight gain (g)	Total protein consumed (g)	PER[3]	Relative PER ratio[4]
Control	44.59[a]	67.82[c]	26.31[c]	2.56[c]	100.0[c]
KP press					
Mature beef	45.06[a]	-3.04[f]	13.27[e]	-.23[f]	-8.85[f]
Young beef	43.80[a]	11.33[e]	15.84[e]	.69[e]	27.13[e]
Mature pork	44.85[a]	89.79[b]	31.47[b]	2.84[ab]	111.24[ab]
Young pork	45.25[a]	80.13[b]	29.36[b]	2.73[bc]	106.65[bc]
Yieldmaster deboner					
Mature beef	44.85[a]	31.59[d]	20.11[d]	1.57[d]	61.33[d]
Young beef	45.21[a]	27.19[d]	20.30[d]	1.33[d]	52.14[d]
Mature pork	44.57[a]	105.43[a]	36.24[a]	2.91[ab]	113.83[ab]
Young pork	44.76[a]	113.04[a]	36.72[a]	3.06[a]	119.84[a]
s.e.m.	1.31	3.75	.31	.08	3.31

[1]Means are averages for 10 rats fed for 28 days. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

[3]PER (protein efficiency ratio) = weight gained/weight of protein consumed.

[4]Relative PER ratio = PER of treatment group x 100/PER of casein control group.

from the KP press and Yieldmaster deboning processes did not consume as much protein and therefore gained less weight than rats fed the casein control or MPPP diets, resulting in lower PER values. Rats which were fed the MPPP from the KP press gained equivalent amounts of weight to those fed the casein control and also consumed more protein, resulting in slightly higher PER values than for the group fed the casein diet. A significantly greater PER ($p < .05$) was observed with the group of rats fed the diets containing MPPP produced by the Yield-master deboner. Expressing the PER of treatment groups on a basis relative to the PER of rats fed the casein diet did not alter the differences in growth which were observed. The cage location had no effect on the amount of feed consumed or growth rate (Appendix Table A.18). Field and Chang (1977) showed that lower PER values were obtained from feeding beef deboned meat diets compared to lamb deboned meat diets, and concluded that closely trimmed bones often produce deboned meat with lower PER values and higher levels of bone marrow and collagen. In the present study, however, only slight compositional differences in the different MP(S)P samples were observed. Appendix Table A.13 reveals a higher content of iron in beef deboned meat samples than in the MPPP. This slight increase in iron content may cause the diets to be unpalatable to the rats fed the MPBP formulations, and so only enough feed to maintain body weight was consumed by the rats. MacNeil et al. (1979) reported very low PER values for rats fed turkey deboned meat. This product had very high TBA values from oxidation of the fat. When an antioxidant was added to the diet, adjusted PER values of the rats fed deboned turkey meat diets were greater than for rats fed

casein control diets. In their study, .17 percent iron was present in the mechanically deboned turkey meat (MacNeil et al., 1979). In the present study, the iron content was .05 percent for MPBP samples, suggesting that some oxidative rancidity may have developed in the corn oil present in the diet formulation, although no tests of rancidity were performed to confirm this possibility. The differences in protein quality seen with the PER growth assays were not observed by the amino acid analyses of MP(S)P samples, which showed that PER measurements of protein quality do not adequately measure the true protein quality of mechanically processed (species) product.

Mechanically processed (species) product (MP(S)P) was produced from bones of different types and ages with two different types of mechanical deboning machines. It appears from the results, that greater amounts of lean tissue must be left on the bones by commercial trimming than is left by present boning practices if MP(S)P is to meet the proximate composition requirements established by the USDA. No large differences in proximate composition of MP(S)P were evident between the press type deboner and rotary type deboner utilized, although the seive openings of the rotary deboner were smaller in size than the separating ring assembly used in the press, resulting in smaller bone particle sizes.

Nutritional quality of the protein was evaluated by amino acid analysis and protein efficiency ratio growth trials. The protein efficiency ratio (PER) showed that MP(S)P produced from pork bones by the Yieldmaster deboner was a higher quality protein than the casein control diet. Other MP(S)P treatments were lower in quality than the

casein control, although the amino acid analysis revealed greater than 33 percent of the amino acids were essential amino acids for all of the treatments of MP(S)P tested. It appears from this study that caution must be exercised in type of bones and deboner operation utilized to produce a satisfactory mechanically processed (species) product that meets all of the compositional limitations imposed by the USDA.

CONCLUSIONS

These studies have revealed new information on chemical, physical, and nutritional quality of mechanically processed (species) product. Satisfactory frankfurters were made from formulations which contained 30 percent or less MPPP. The emulsions were stable after heat processing although increased levels of MPPP caused a softer texture than control formulations. The frankfurters were produced in a Hobart laboratory chopper which differs in emulsification than a commercial scale cutter. The Hobart chopper was useful in suggesting trends observed in the larger Kramer-Grebe chopper, but data could not be extrapolated directly from one system to the other. This suggests that further studies on the use of MP(S)P in commercial systems are necessary to determine if increases in water-holding capacity as observed in the Hobart manufacture would also occur under manufacturing conditions in the Kramer-Grebe commercial chopper. Determinations of smokehouse yield and emulsion stability of commercially sized batches of frankfurters containing progressive levels of MP(S)P would aid meat processors in decisions on levels of usage in commercial frankfurter production. The differences between the emulsification efficiencies and emulsion properties observed for the Hobart and Kramer-Grebe cutters suggested that further studies on differences in emulsion characteristics might be useful in elucidation of the factors which cause emulsion instability in commercial manufacture.

Mechanically processed (species) product was manufactured to determine if a similar composition of the product produced by a

hydraulic press deboner and a rotary deboner existed. It was concluded that bone type and amount of lean left adhering to the bones after commercial trimming influences the composition more than deboner type. The rotary deboner tended to produce fewer and smaller bone particles in the MP(S)P than the KP press although a direct comparison of the two deboners was invalid due to the deboning procedures employed. Only slight differences in moisture, fat, and protein existed between MP(S)P from beef and pork species and between back and blade bones, but larger differences in ash and bone content were observed. Processing of frozen bones by deboning deserves further study to determine if the smaller bone particles produced were a result of the freezing process, deboning process, or an artifact present in this study.

The nutritional protein quality appeared to meet the essential amino acid content, but rats did not appear to grow on diets containing MPBP. Beef contains more heme pigments and so they may cause lipid oxidation to be increased. Samples of MPBP were greater in iron content than samples of MPPP, indicating greater heme pigment concentrations. The MP(S)P produced in these studies appears to be quite satisfactory as an alternative protein source and would be improved if commercial boning operations left more lean adhering to the bones.

ACKNOWLEDGEMENTS

The author is deeply indebted to his major professor, Dr. David G. Topel, for the guidance, counsel, and understanding given during this study. The support and efforts of Dr. Joseph G. Sebranek, Professor Robert E. Rust, Dr. Homer W. Walker, and Dr. Richard C. Ewan while serving on the author's graduate committee were very much appreciated.

The use of the facilities in the meat laboratory and Animal Science Department is gladly acknowledged. Financial support from the Kartridg-Pak Company, Davenport, Iowa, and the helpfulness and cooperation of Mr. Ray Keating, Mr. Gary Steinke, and Mr. Gary Woodworth were invaluable for completion of this research.

The friendship and encouragement provided by Dr. Edwin A. Kline were very gratifying, and the help and support by the graduate students, staff, and laboratory assistants were highly valued. A special thanks is given to Mr. Randy Petersohn and Mr. Grant Gustafson and the meat laboratory employees for their cooperation and patience.

The author is grateful to his family and friends for their faith and understanding. Sincere appreciation for the knowledge and ability to conduct this study and the wisdom gained is expressed to the Author of all things.

Many thanks must be given to my wife Deb. This research and dissertation have been completed only through the understanding, patience, help, comfort, and love she has shown.

BIBLIOGRAPHY

AOAC. 1975. Official methods of analysis. 12th ed. Association of Official Analytical Chemists, Washington, D.C.

Ackerman, S. A., C. E. Swift, R. J. Carroll, and W. E. Townsend. 1971. Effects of types of fat and of rates and temperatures of comminution on dispersion of lipids in frankfurters. J. Food Sci. 36: 266-269.

Ackerman, S. A., A. J. Miller, and C. E. Swift. 1979. A phase testing method for rapidly determining the stability of sausage emulsions. J. Food Sci. 44: 174-176.

Acton, J. C., and R. L. Saffle. 1969. Preblended and pre-rigor meat in sausage emulsions. Food Technol. 23: 367-371.

Acton, J. C., and R. L. Saffle. 1972a. Film observations at an oil-water interface. J. Food Sci. 37: 795-796.

Acton, J. C., and R. L. Saffle. 1972b. Emulsifying capacity of muscle protein: phase volumes at emulsion collapse. J. Food Sci. 37: 904-906.

Alsmeyer, R. H., A. E. Cunningham, and M. L. Happich. 1974. Equations predict PER from amino acid analysis. Food Technol. 28(7): 34-40.

Altschul, A. M. 1974. Chapter I. Protein food technologies and the politics of food: an overview. In A. M. Altschul, ed. New protein foods. Academic Press, New York.

Anderson, J. R., and T. A. Gillett. 1974. Extractable-emulsifying capacity of hand and mechanically deboned mutton. J. Food Sci. 39: 1147-1149.

Angel, S., J. M. Darfler, L. F. Hood, and R. C. Baker. 1974. Frankfurters made from mechanically deboned poultry meat (MDPM). 2. Microscopy. Poul. Sci. 53: 166-174.

Anonymous. 1975a. 8 Firms offer deboning machines; how they work. National Provisioner 172(14): 12, 32, 42-50.

Anonymous. 1975b. Recaptured protein. Meat Industry Magazine 21(12): 22-23.

Anonymous. 1976. Deboning. Food Technol. 30(7): 72-76.

Baker, R. C., and J. M. Darfler. 1975. Acceptability of frankfurters made from mechanically deboned turkey frames as affected by formulation changes. Poul. Sci. 54: 1283-1288.

Baker, R. C., J. M. Darfler, and S. Angel. 1974. Frankfurters made from mechanically deboned poultry meat (MDPM). 1. Effect of chopping time. Poul. Sci. 53: 156-161.

Bard, J. C. 1965. Some factors affecting extractability of salt-soluble proteins. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 96-98.

Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. 1976. A user's guide to SAS. SAS Institute, Raleigh, N.C. 329 pp.

Becher, P. 1965. Emulsions: theory and practice. 2nd ed. Reinhold Publishing Corp., New York. 440 pp.

Bell, T. D., L. E. Orme, C. W. Hodgson, R. E. Christian, and D. O. Everson. 1967. Weanling and carcass characteristics of purebred and crossbred Rambouillet, Targhee and Panama lambs. Univ. of Idaho Exp. Sta. Res. Bull. 75.

Berry, B. W. 1978. Use of mechanically deboned and mechanically desinewed beef in meat products. Proc. 20th Ann. Meat Sci. Inst. (Univ. of Georgia, Athens, Ga.). pp. 1-12.

Berry, B. W., H. R. Cross, A. L. Joseph, S. B. Wagner, and J. A. Maga. 1979. Sensory and physical measurements of dry fermented salami prepared with mechanically processed beef product and structured soy protein fiber. J. Food Sci. 44: 465-468, 474.

Binkerd, E. F., R. H. Forsythe, R. L. Hendrickson, R. J. Ives, O. E. Kolari, and C. Tracy. 1978. Animal protein from meat, poultry and eggs. Pages 397-399 in M. Milner, N. S. Scrimshaw, and D. I. C. Wang, eds. Protein resources and technology: status and research needs. AVI Publishing Co., Inc., Westport, Conn. 629 pp.

Borchert, L. L., M. L. Greaser, J. C. Bard, R. G. Cassens, and E. J. Briskey. 1967. Electron microscopy of a meat emulsion. J. Food Sci. 32: 419-421.

Borton, R. J., N. B. Webb, and L. J. Bratzler. 1968. Emulsifying capacities and emulsion stability of dilute meat slurries from various meat trimmings. Food Technol. 22: 506-508.

Brennan, J. G. 1970. Emulsions in food technology. Process Biochem. 5(7): 33-37.

Brinkman, G. L., and J. H. MacNeil. 1976. Protein quality of mechanically deboned poultry meat as measured by rat PER. Nutr. Reports Intnl. 14: 365-369.

Briskey, E. J., W. G. Hoekstra, R. G. Bray, and R. H. Grummer. 1960. A comparison of certain physical and chemical characteristics of eight pork muscles. J. Anim. Sci. 19: 214-225.

Brooks, C. C., H. R. Thomas, R. F. Kelly, P. P. Graham, and L. B. Allen. 1964. Body composition and feed efficiency changes in swine. Virginia Polytechnic Inst. Agr. Exp. Sta. Tech. Bull. 176.

Brown, D. D., and R. T. Toledo. 1975. Relationship between chopping temperatures and fat and water binding in comminuted meat batters. J. Food Sci. 40: 1061-1064.

Brown, W. L. 1975. New proteins offer exciting possibilities. National Prov. 172(14): 45-48.

Burr, I. W. 1974. Applied statistical methods. Academic Press, New York. 479 pp.

Carpenter, J. A., and R. L. Saffle. 1964. A simple method of estimating the emulsifying capacity of various sausage meats. J. Food Sci. 29: 774-781.

Cassens, R. G., R. Schmidt, R. Terrell, and L. L. Borchert. 1977. Microscopic structure of commercial sausage. Univ. of Wisconsin Res. Report R-2878.

Chang, Y. O., and R. A. Field. 1977. Protein utilization of mechanically deboned meat by growing rats. J. Nutrition 107: 1947-1953.

Chant, J. L., L. Day, R. A. Field, W. G. Kruggel, and Yet-oy Chang. 1977. Composition and palatability of mechanically deboned meat and mechanically separated tissue. J. Food Sci. 42: 306-309.

Christian, J. A., and R. L. Saffle. 1967. Plant and animal fats and oils emulsified in a model system with muscle salt-soluble protein. Food Technol. 21: 1024-1027.

Connell, J. J. 1955. Modification of Grau and Hamm's method for the determination of water-binding. Naturwissenschaften 42: 443.

Craddock, B. F., R. A. Field, and M. L. Riley. 1974. Effect of protein and energy levels on lamb carcass composition. J. Anim. Sci. 39: 325-330.

Cross, H. R., J. Stroud, Z. L. Carpenter, A. W. Kotula, T. W. Nolan, and G. C. Smith. 1977. Use of mechanically deboned meat in ground beef patties. J. Food Sci. 42: 1496-1499.

Cross, H. R., A. W. Kotula, and T. W. Nolan. 1978a. Stability of frozen ground beef containing mechanically deboned beef. J. Food Sci. 43: 281-284.

Cross, H. R., B. W. Berry, J. E. Nichols, R. S. Elder, and J. A. Quick. 1978b. Effect of desinewing vs. grinding on textural properties of beef. J. Food Sci. 43: 1507-1509.

Cuthbertson, A., and R. W. Pomeroy. 1962. Quantitative anatomical studies of the composition of the pig at 50, 68, and 92 kg. carcass weight. II. Gross composition and skeletal composition. J. Agric. Sci. 59: 215-223.

Dhillon, A. S., and A. J. Maurer. 1975a. Utilization of mechanically deboned chicken meat in the formulation of summer sausages. Poul. Sci. 54: 1164-1174.

Dhillon, A. S., and A. J. Maurer. 1975b. Quality measurements of chicken and turkey summer sausages. Poul. Sci. 54: 1263-1271.

Doyle, J. J. 1979. Toxic and essential elements in bone - a review. J. Anim. Sci. 49: 482-497.

Draper, N. R., and H. Smith. 1966. Applied regression analysis. John Wiley and Sons, Inc., New York. 407 pp.

Duncan, D. B. 1955. New multiple range and multiple F tests. Biometrics 11: 1.

Dvorak, Z. 1972. The use of hydroxyproline analyses to predict the nutritional value of the protein in different animal tissues. Br. J. Nutr. 27: 475-481.

Emswiler, B. S., C. J. Pierson, A. W. Kotula, and H. R. Cross. 1978. Microbiological evaluation of ground beef containing mechanically deboned beef. J. Food Sci. 43: 158-161.

Essary, E. O., and S. J. Ritchey. 1968. Amino acid composition of meat removed from boned turkey carcasses by use of commercial boning machine. Poul. Sci. 47: 1953-1955.

Ewan, R. C., D. G. Topel, and K. Ono. 1979. Chemical composition of chops from pale, soft, exudative (PSE) and normal pork loins. J. Food Sci. 44: 678-680.

Farmer, B. R., A. W. Mahoney, D. G. Hendricks, and T. A. Gillett. 1977. Iron bioavailability of hand-boned and mechanically deboned beef. J. Food Sci. 42: 1630-1632.

Federal Register. 1976a. Definition of meat recovered by mechanical means and by low temperature rendering techniques. Fed. Reg. 41(82): 17535.

Federal Register. 1976b. Definition of meat and classes of meat, permitted uses, and labelling requirements. Fed. Reg. 41(82): 17560-17566.

Federal Register. 1977. Standards and labeling requirements for tissue from ground bone. Fed. Reg. 42(194): 54437-54442.

Federal Register. 1978. Mechanically processed (species) product. Standards and labeling requirements. Fed. Reg. 43(119): 26416-26425.

Field, R. A. 1974. Mechanically deboned meat. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 96-98.

Field, R. A. 1975. Recovery of protein from bones by mechanical deboners. 21st European Meeting of Meat Research Workers. (Bern, Switzerland.) p. 100.

Field, R. A. 1976a. Increased animal production with mechanical deboners. World Rev. of Anim. Prod. 12(1): 61-73.

Field, R. A. 1976b. Mechanically-deboned red meat. Food Technol. 30(9): 38-48.

Field, R. A., and M. L. Riley. 1974. Characterization of meat from mechanically deboned lamb breasts. J. Food Sci. 39: 851-852.

Field, R. A., and M. L. Riley. 1975. Specific gravity estimates of bone composition. Proc. Western Sec. Amer. Soc. Anim. Sci. 26: 70-73.

Field, R. A., M. L. Riley, and M. P. Botkin. 1967. Effect of sex and ram weight on composition of lambs. Proc. Western Sec. Amer. Soc. Anim. Sci. 18: 45.

Field, R. A., M. L. Riley, and M. H. Corbridge. 1974a. Influence of yield on calcium content of mechanically deboned lamb and mutton. J. Food Sci. 39: 285-287.

Field, R. A., M. L. Riley, and M. H. Corbridge. 1974b. Characterization of mechanically deboned hot and cold mutton carcasses. J. Food Sci. 39: 282-284.

Field, R. A., M. L. Riley, F. C. Mello, M. H. Corbridge, and A. W. Kotula. 1974c. Bone composition in cattle, pigs, sheep and poultry. J. Anim. Sci. 39: 493-499.

Field, R. A., W. G. Kruggel, M. L. Riley, and J. L. Chant. 1975. Protein yields from bones destined for processing. Proc. Western Sec. Amer. Soc. Anim. Sci. 26: 74-77.

Field, R. A., S. L. Olson-Womack, and W. G. Kruggel. 1977. Characterization of bone particles from mechanically deboned meat. J. Food Sci. 42: 1406-1407.

Field, R. A., Y. Chang, and W. G. Kruggel. 1979. Protein quality of mechanically processed (species) product and bone residue. J. Food Sci. 44: 690-692, 695.

Forrest, J. C., E. D. Aberle, H. B. Hedrick, M. D. Judge, and R. A. Merkel. 1975. Principles of meat science. W. H. Freeman and Co., San Francisco, Ca. 417 pp.

Forsythe, R. H., and E. J. Briskey. 1977. Outlook for alternative protein sources in processed foods. Pages 554-570 in J. R. Whitaker and S. R. Tannenbaum, eds. Food proteins. AVI Publishing Co., Inc., Westport, Conn. 603 pp.

Fried, I. 1976. Regulatory considerations concerning mechanically-deboned red meat. Food Technol. 30(9): 35-37, 70.

Froning, G. W. 1970. Poultry meat sources and their emulsifying characteristics as related to processing variables. Poul. Sci. 49: 1625-1631.

Froning, G. W. 1976. Mechanically-deboned poultry meat. Food Technol. 30(9): 50-63.

Froning, G. W. 1979. Characteristics of bone particles from various poultry meat products. Poul. Sci. 58: 1001-1003.

Froning, G. W., and D. Janky. 1971. Effect of pH and salt preblending on emulsifying characteristics of mechanically deboned turkey frame meat. Poul. Sci. 50: 1206-1209.

Froning, G. W., R. G. Arnold, R. W. Mandigo, C. E. Neth, and T. E. Hartung. 1971. Quality and storage stability of frankfurters containing 15% mechanically deboned turkey meat. J. Food Sci. 36: 974-978.

Gillett, T. A., K. Tantikarnjathep, and S. J. Andrews. 1976. Mechanically desinewed meat: its yield, composition and effect on palatability of cooked salami. J. Food Sci. 41: 765-769.

Gillett, T. A., D. E. Meiburg, C. L. Brown, and S. Simon. 1977. Parameters affecting meat protein extraction and interpretation of model system data for meat emulsion formation. J. Food Sci. 42: 1606-1610.

Goldstrand, R. E. 1975. Mechanically deboned meats yields and product characteristics. Proc. 28th Ann. Recip. Meat Conf. of Am. Meat Sci. Assn., Univ. of Missouri, Columbia, Mo. pp. 116-125.

Gong, J. K., and J. S. Arnold. 1965. Skeletal marrow volume in dog. Amer. J. Physiol. 209: 340-346.

Gorbatov, A. V., and V. M. Gorbatov. 1974. Advances in sausage meat rheology. J. Texture Studies 4: 406-437.

Gordon, A. 1969a. Emulsification in comminuted meat systems. Part 1. A review of recent research. Food Proc. Industry 38(458): 54-56.

Gordon, A. 1969b. Emulsification in comminuted meat systems. A review of recent research. Part 2. Food Proc. Industry 38(459): 50-52, 54.

Gornall, A. G., C. J. Bardawill, and M. M. David. 1949. Determination of serum proteins by means of the biuret reaction. J. Biol. Chem. 177: 751-766.

Grau, R., and R. Hamm. 1953. Eine einfache methode zur bestimmung der wasserbindung im muskel. Naturwissenschaften 40: 29-30.

Grunden, L. P., and J. H. MacNeil. 1973. Examination of bone content in mechanically deboned poultry meat by EDTA and atomic absorption spectrophotometric methods. J. Food Sci. 38: 712-713.

Grunden, L. P., J. H. MacNeil, and P. S. Dimick. 1972. Poultry product quality: chemical and physical characteristics of mechanically deboned poultry meat. J. Food Sci. 37: 247-249.

Hamm, R. 1959. Biochemistry of meat hydration. Proc. 11th Res. Conf. (Am. Meat Inst. Found., Chicago, Ill.). pp. 17-23.

Hamm, R. 1960. Biochemistry of meat hydration. Adv. in Food Res. 10: 355-463.

Hamm, R., and F. E. Deatherage. 1960. Changes in hydration, solubility and protein charges of muscle proteins during heating of meat. Food Res. 25: 587-610.

Hansen, L. J. 1960. Emulsion formation in finely comminuted sausage. Food Technol. 14: 565-569.

Happich, M. L., R. A. Whitmore, S. Feairheller, M. M. Taylor, C. E. Swift, and J. Naghski. 1975. Composition and protein efficiency ratio of partially defatted chopped beef and of partially defatted beef fatty tissue and combinations with selected proteins. J. Food Sci. 40: 35-39.

Hegarty, G. R., L. J. Bratzler, and A. M. Pearson. 1963. Studies on the emulsifying properties of some intracellular beef muscle proteins. J. Food Sci. 43: 312-314, 330.

Hegsted, D. M. 1977. Protein quality and its determination. Pages 347-362 in J. R. Whitaker and S. R. Tannenbaum, eds. Food proteins. AVI Publishing Co., Inc., Westport, Conn. 603 pp.

Helmer, R. L., and R. L. Saffle. 1963. Effect of chopping temperature on the stability of sausage emulsions. Food Technol. 17: 1195-1197.

Hendricks, D. G., A. W. Mahoney, and T. A. Gillett. 1977. Influence of removing connective tissue, cooking, nitrite curing on protein quality of beef shank muscle. J. Food Sci. 42: 186-189.

Hill, R. M., and D. B. Hites. 1968. Determination of small bone particles in meat. J. AOAC 51: 1175-1177.

IFT (Institute of Food Technologists) Expert Panel. 1979. Mechanically deboned red meat, poultry, and fish. Food Technol. 33(3): 77-79.

Ivey, F. J., N. B. Webb, and V. A. Jones. 1970. The effect of disperse phase droplet size and interfacial film thickness on the emulsifying capacity and stability of meat emulsions. Food Technol. 24: 1279-1281.

Johnson, R. I. 1946. The design of emulsifying machines. Pages 88-89 in H. Bennett, ed. Emulsion technology. 2nd ed. Chemical Publishing Co., Brooklyn, New York. 568 pp.

Johnson, H. R., E. D. Aberle, J. C. Forrest, C. G. Haugh, and M. D. Judge. 1977. Physical and chemical influences on meat emulsion stability in a model emulsitator. J. Food Sci. 42: 522-531.

Joseph, A. L., B. W. Berry, H. R. Cross, and J. A. Maga. 1978. Utilization of mechanically deboned beef in cooked salami. J. Food Sci. 43: 307-311.

Kelly, R. F., J. P. Fontenot, P. P. Graham, W. S. Wilkinson, and C. M. Kincaid. 1968. Estimates of carcass composition of beef cattle fed at different planes of nutrition. J. Anim. Sci. 27: 620-627.

Kemp, J. D., and R. A. Barton. 1969. Composition of cuts and carcasses of New Zealand lamb when graded by United States grade standards. J. Anim. Sci. 28: 324-330.

Kemp, J. D., J. D. Crouse, W. Dewesse, and W. G. Moody. 1970. Effect of slaughter weight and castration on carcass characteristics of lambs. J. Anim. Sci. 30: 348-354.

Kolbye, Albert, Merlin A. Nelson, and Elizabeth W. Murphy. 1977. Health and safety aspects of the use of mechanically deboned meat. Volume I. Final report and recommendations, select panel. Food Safety and Quality Service, U.S. Dept. of Agric., Washington, D.C. 79 pp.

Kramlich, W. E. 1971. Sausage products. Pages 484-512 in J. F. Price and B. S. Schweigert, eds. The science of meat and meat products. 2nd ed. W. H. Freeman and Company, San Francisco, Ca. 660 pp.

Kramlich, W. E., A. M. Pearson, and F. W. Tauber. 1973. Processed meats. AVI Publishing Co., Inc., Westport, Conn. 348 pp.

Kruggel, W. G., and R. A. Field. 1977. Fluoride content of mechanically deboned beef and pork from commercial sources in different geographical areas. J. Food Sci. 42: 190-192.

Kunsman, J. E., and R. A. Field. 1973. The effect of mechanical deboning on hydrolysis and oxidation of lamb fat. Proc. Western Sec. Am. Soc. Anim. Sci. 24: 112-115.

Kunsman, J. E., R. A. Field, and D. Kazantzis. 1978. Lipid oxidation in mechanically deboned red meat. J. Food Sci. 43: 1375-1378.

Lee, Y. B., G. L. Hargus, J. A. Kilpatrick, D. L. Berner, and R. H. Forsythe. 1975. Mechanism of lipid oxidation in mechanically deboned chicken meat. J. Food Sci. 40: 964-967.

Lee, Y. B., J. G. Elliott, D. A. Rickansrud, and E. C. Hagberg. 1978. Predicting protein efficiency ratio by the chemical determination of connective tissue content in meat. J. Food Sci. 43: 1359-1362.

Lehninger, A. L. 1975. Biochemistry. 2nd ed. Worth Publishers, Inc., New York. 1104 pp.

Lutwak, L. 1974. Dietary calcium and the reversal of bone demineralization. Nutr. News 37(1): 1.

Lutwak-Mann, C. 1952. Some aspects of phosphorus metabolism in bone marrow. 2. Changes in the content of phosphorus compounds and reducing substances in bone marrow and spleen, caused by ionizing radiation and other factors which depress the function of blood-forming tissue. Biochem. J. 52: 356-364.

MacNeil, J. H., M. G. Mast, and R. M. Leach. 1978. Protein efficiency ratio and levels of selected nutrients in mechanically deboned poultry meat. J. Food Sci. 43: 864-865, 869.

MacNeil, J. H., M. G. Mast, and R. M. Leach. 1979. Protein efficiency ratio and amounts of selected nutrients in mechanically deboned turkey meat. J. Food Sci. 44: 1291-1293, 1298.

Marshall, W. H., G. C. Smith, T. R. Dutson, and Z. L. Carpenter. 1977. Mechanically deboned goat, mutton and pork in frankfurters. J. Food Sci. 42: 193-196.

Martinez-Torres, C., I. Leets, M. Renzi, and M. Layrisse. 1974. Iron absorption by humans from veal liver. J. Nutr. 104: 983-993.

Maxcy, R. B., G. W. Froning, and T. E. Hartung. 1973. Microbial quality of ground poultry meat. Poul. Sci. 52: 486-491.

Maynard, L. A., and J. K. Loosli. 1979. Animal nutrition. 7th ed. McGraw-Hill Book Co., Inc., New York. 602 pp.

Meiburg, D. E., K. E. Beery, C. L. Brown, and S. Simon. 1976. Studies on the utilization of mechanically deboned and mechanically separated meat. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 79-98.

Mello, F. C., R. A. Field, and M. L. Riley. 1978. Effect of age and anatomical location on composition of bovine bone. J. Food Sci. 43: 677-679.

Miller, W. O., R. L. Saffle, and S. B. Zirkle. 1968. Factors which influence the water-holding capacity of various types of meat. Food Technol. 33: 1139-1142.

Misock, J. P., J. E. Kunsman, and R. A. Field. 1979. Lipid oxidation in bologna containing mechanically deboned beef. J. Food Sci. 44: 151-153.

Mitchell, H. H. 1964. Comparative nutrition of man and domestic animals. Vol. II. Academic Press, New York. 672 pp.

Mittal, K. L. 1971. Conceptual clarification of the terms used to describe emulsion behavior. J. Soc. Cosmet. Chem. 22: 815-824.

Moerck, K. E., and H. R. Ball, Jr. 1974. Lipid autoxidation in mechanically deboned chicken meat. J. Food Sci. 39: 876-879.

Morrison, G. S., N. B. Webb, T. N. Blumer, F. J. Ivey, and A. Haq. 1971. Relationship between composition and stability of sausage-type emulsions. J. Food Sci. 36: 426-430.

Munson, A. W., L. E. Walters, and J. V. Whiteman. 1964. Relationship of some growth factors with carcass composition in milk fat wether lambs. Oklahoma Agr. Exp. Sta. MP-74.

National Hot Dog and Sausage Council. 1979. The hot dog fact sheet. The National Hot Dog and Sausage Council, Chicago, Ill.

Noble, J. 1976. Mechanically deboned meat: used worldwide for very good reasons. Food Eng. 48(11): 90-97.

Ostovar, K., J. H. MacNeil, and K. O'Donnell. 1971. Poultry product quality. 5. Microbiological evaluation of mechanically deboned poultry meat. J. Food Sci. 36: 1005-1007.

Pauly, M. R. 1967. Machine deboned poultry and what to do with the meat. Proc. of Poultry and Egg Further Processing Conf., Ohio State Univ., Columbus, Ohio.

Petrowski, G. E. 1976. Emulsion stability and its relation to foods. Adv. in Food Res. 22: 309-359.

Price, M. A., and N. T. M. Yeates. 1969. Growth rates and carcass characteristics in steers and partial castrates. Page 69 in D. N. Rhodes, ed. Meat production from entire male animals. J. and A. Churchill Ltd., London, England. 332 pp.

Ray, F. K., B. G. Miller, D. C. Van Sickle, E. D. Aberle, J. C. Forrest, and M. D. Judge. 1979. Identification of fat and protein components in meat emulsions using SEM and light microscopy. Scanning Electron Microscopy 3: 473-478.

Richmond, R. J., and R. T. Berg. 1971. Tissue development in swine as influenced by liveweight, breed, sex and ration. Can. J. Anim. Sci. 51: 31-39.

Rongey, E. J. 1965. A simple objective test for sausage emulsion quality. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 99-106.

Rouse, G. H., D. G. Topel, R. L. Vetter, R. E. Rust, and T. W. Wickersham. 1970. Carcass composition of lambs at different stages of development. J. Anim. Sci. 31: 846-855.

Rust, R. E. 1977. Sausage and processed meats manufacturing. AMI Center for Continuing Education, American Meat Institute, Arlington, Va. 153 pp.

Saffle, R. L. 1968. Meat emulsions. Adv. in Food Res. 16: 105-160.

Saffle, R. L., and J. W. Galbreath. 1964. Quantitative determination of salt-soluble protein in various types of meat. Food Technol. 18: 1943-1944.

Satterlee, L. D., G. W. Froning, and D. M. Janky. 1971. Influence of skin content on composition of mechanically deboned poultry meat. J. Food Sci. 36: 979-981.

Schmidt, G. R. 1979. New methods in meat processing. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 31-40.

Schnell, P. G., K. P. Nath, J. M. Darfler, D. V. Vadehra, and R. C. Baker. 1973. Physical and functional properties of MDPM as used in the manufacture of frankfurters. Poul. Sci. 52: 1363-1369.

Schut, J. 1976. Meat emulsions. Pages 385-458 in S. Friberg, ed. Food emulsions. Marcel Dekker Inc., New York.

Schut, J. 1978a. The European sausage industry. Proc. 31st Ann. Recip. Meat Conf. of Am. Meat Sci. Assn., Univ. of Connecticut, Storrs, Conn. pp. 5-12.

Schut, J. 1978b. Basic meat emulsion technology. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 1-15.

Seideman, S. C., G. C. Smith, and Z. L. Carpenter. 1977. Addition of textured soy protein and mechanically deboned beef to ground beef formulations. J. Food Sci. 42: 197-201.

Shannon, W. J. 1978. Manufacturing techniques for sausage emulsion production. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 41-45.

Sherman, P. 1961. The water binding capacity of fresh pork. I. The influence of sodium chloride, pyrophosphate, and polyphosphate on water absorption. Food Technol. 15: 79-87.

Sherman, P. 1962. The water binding capacity of fresh pork. 4. The influence of ion absorption from neutral salts and polyphosphate on water retention by lean pork. Food Technol. 16: 91-95.

Simon, S., J. C. Field, W. E. Kramlich, and F. W. Tauber. 1965. Factors affecting frankfurter texture and a method of measurement. Food Technol. 19: 410-413.

Stamm, A. J., and E. O. Kramer. 1926. A note on the mechanism of emulsification. J. Phys. Chem. 30: 996-1000.

Starr, L. D. 1979. What's new in the old technologies: cooking, chopping and converting. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 41-48.

Steel, R. G., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., New York. 481 pp.

Stilwell, D. E., R. W. Mandigo, G. M. Weiss, and J. F. Campbell. 1978. Accelerated pork processing: frankfurter emulsion properties. J. Food Sci. 43: 1646-1647.

Sulzbacher, W. L. 1973. Meat emulsions. J. Sci. Food and Agric. 24: 589-595.

Sulzbacher, W. L., and C. E. Swift. 1970. Processing factors and emulsion characteristics. 16th European Meeting of Meat Research Workers, Vol. 16. (Varna, Golden Sands, Bulgaria).

Swift, C. E., and R. Ellis. 1956. The action of phosphates in sausage products. I. Factors affecting the water retention of phosphate-treated ground meat. Food Technol. 10: 546-552.

Swift, C. E., and W. L. Sulzbacher. 1963. Comminuted meat emulsions: factors affecting meat proteins as emulsion stabilizers. Food Technol. 17: 224-226.

Swift, C. E., C. Lockett, and A. J. Fryar. 1961. Comminuted meat emulsions - the capacity of meats for emulsifying fat. Food Technol. 15: 468-473.

Swift, C. E., W. E. Townsend, and L. P. Witnauer. 1968. Comminuted meat emulsions: relation of the melting characteristics of fat to emulsion stability. Food Technol. 22: 775-778.

Tauber, F. W. 1976. The history of sausage. Proc. 29th Ann. Recip. Meat Conf. of Am. Meat Sci. Assn., Brigham Young Univ., Provo, Utah. pp. 55-59.

Terrell, R. N. 1974. Theory and practice of preblending for use in comminuted meat food mixes. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 23-33.

Theno, D. M., and G. R. Schmidt. 1978. Microstructural comparisons of three commercial frankfurters. J. Food Sci. 43: 845-848.

Tinbergen, B. J., and W. J. Olsman. 1979. Fat cell rupture in a comminuted meat batter as a determinative factor of heat stability. J. Food Sci. 44: 693-695.

Townsend, W. E. 1976. Measuring stability of meat batters. Proc. 18th Ann. Meat Sci. Inst. (Univ. of Georgia, Athens, Ga.). pp. 10-16.

Townsend, W. E., L. P. Witnauer, J. A. Riloff, and C. E. Swift. 1968. Comminuted meat emulsions: differential thermal analysis of fat transitions. Food Technol. 22: 319-323.

Trautman, J. C. 1964. Fat emulsifying properties of prerigor and post-rigor pork proteins. Food Technol. 18: 1065-1066.

Tsai, R., R. G. Cassens, and E. J. Briskey. 1972. Emulsifying properties of purified muscle proteins. J. Food Sci. 37: 286-288.

Waldman, R. C., D. O. Westerberg, and S. Simon. 1974. Influence of curing ingredients and storage time on the quality of preblended sausage meats and frankfurters. J. Food Sci. 39: 718-722.

Walker, A. R. P. 1972. The human requirement of calcium: should low intakes be supplemented? Am. J. Clin. Nutr. 25: 518-530.

Watt, B. K., and A. L. Merrill. 1963. Composition of foods: raw, processed, prepared. USDA Agricultural Handbook No. 8. (U.S. Government Printing Office, Washington, D.C.). 189 pp.

Webb, N. B. 1974. Emulsion technology. Proc. Meat Industry Res. Conf. (Am. Meat Inst. Found., Arlington, Va.). pp. 1-15.

Webb, N. B., V. N. M. Rao, A. J. Howell, B. C. Barbour, and R. J. Monroe. 1975. Effect of lipid and chopping temperatures on sausage emulsion stability in a model system. J. Food Sci. 40: 1210-1213.

Wierbicki, E., and F. E. Deatherage. 1958. Determination of water-holding capacity of fresh meats. J. Agr. and Food Chem. 6: 387-392.

Wierbicki, E., L. E. Kunkle, and F. E. Deatherage. 1957. Changes in the water-holding capacity and cationic shifts during the heating and freezing and thawing of meat as revealed by a simple centrifugal method for measuring shrinkage. Food Technol. 11: 69-73.

Wiley, E. J., J. O. Reagan, J. A. Carpenter, and D. R. Campion. 1979. Connective tissue profiles of various sausage raw materials. J. Food Sci. 44: 918-919, 921.

Wirth, F. 1978. Advantages of vacuum chopping in sausage manufacturing. Meat Industry Magazine 24(10): 65-66, 144-145.

Zobrisky, S. E. 1969. Bone. Pages 217-235 in E. S. E. Hafez and I. A. Dyer, eds. Animal growth and nutrition. Lea and Febiger, Philadelphia, Penn. 402 pp.

APPENDIX

Table A.1. Sums of squares from analysis of variance for physical characteristics of frankfurters in Part I

Source[a]	d.f.	Emulsion stability		Fluid lost total	Frankfurter diameter	Warner-Bratzler shear force	Shear/area	Smokehouse yield[b]	d.f.
		Water	Fat						
Trt (T)	5	135.40*	21.96**	265.06*	22.00	19.76**	.034**	451.57*	5
Rep (R)	2	1.50	1.36	3.11	2.02	.67	.001	245.82*	2
T x R	10	94.34	7.73*	144.53*	25.32**	2.56**	.003**		
Error	18	76.09	4.67	76.67	5.26	.15	.001	250.52	10
Total	35	307.33	35.72	489.36	54.60	23.15	.039	947.91	17

[a]Model was μ(mean) = $T_i + R_j + TxR_{ij} + E_{ijk}$, where

T = Effect of treatment level of MPPP (0, 10, 20, 30, 40, or 50%), i = 1-6
R = Effect of replication trial (1, 2, or 3), j = 1-3
TxR = Interaction of main effects
E = Error
k = Observations 1 and 2.

[b]Model was μ(mean) = $T_i + R_j + E_{ij}$, where the symbols are the same as above. The interaction of main effects was unable to be included, since only one observation per replication was measured for smokehouse yield.

*$p < .05$.

**$p < .01$.

Table A.2. Sums of squares from analysis of variance for composition of raw emulsions and frankfurters in Part I

Source[a]	d.f.	Percent moisture	Percent fat	Percent protein	Percent ash	Percent bone content	Moisture: protein ratio
				Raw Emulsions			
Trt (T)	5	9.12	4.33	4.85	.55**	.37**	.86
Rep (R)	2	.25	1.23	1.97	.04	.01	.24
T x R	10	17.79**	20.75**	5.62**	.15	.10*	1.05**
Error	18	.75	2.99	1.46	.21	.06	.21
Total	35	27.16	29.30	13.89	.94	.54	2.36
				Frankfurters			
Trt (T)	5	20.27	21.21	.15	.98**	.76*	.07
Rep (R)	2	6.29	6.64	1.07	.05	.03	.11
T x R	10	23.55**	26.88*	7.75**	.20	.38**	.46**
Error	18	6.04	17.19	1.41	.24	.13	.08
Total	35	56.15	71.92	10.38	1.46	1.31	.71

[a]Model was μ(mean) = $T_i + R_j + TxR_{ij} + E_{ijk}$, where

T = Effect of treatment level of MPPP (0, 10, 20, 30, 40, or 50%), i = 1-6
R = Effect of replication trial (1, 2, or 3), j = 1-3
TxR = Interaction of main effects
E = Error
k = Observations 1 and 2.

*$p < .05$.

**$p < .01$.

Table A.3. Sums of squares from analysis of variance for water binding characteristics in Part I

Source[a]	d.f.	Water holding capacity				Expressible juice			
		Raw emulsion		Frankfurter		Raw emulsion		Frankfurter	
		Grid	Planimeter	Grid	Planimeter	Grid	Planimeter	Grid	Planimeter
Trt (T)	5	.53	.65	1.01**	1.54**	1675.54	1783.47	683.40	925.76**
Rep (R)	2	.10	.13	.09	.12*	167.62	186.67	142.27	295.13**
T x R	10	.56**	.48**	.35**	.13	2529.44**	2027.32**	1008.88**	152.26
Error	18	.08	.07	.03	.11	206.95	170.09	64.54	220.97
Total	35	1.25	1.32	1.47	1.91	4579.57	4167.54	1899.08	1594.12

[a]Model was μ(mean) = $T_i + R_j + TxR_{ij} + E_{ijk}$, where

T = Effect of treatment level of MPPP (0, 10, 20, 30, 40, or 50%), i = 1-6
R = Effect of replication trial (1, 2, or 3), j = 1-3
TxR = Interaction of main effects
E = Error
k = Observations 1 and 2.

*$p < .05$.

**$p < .01$.

Table A.4. Sums of squares from analysis of variance for composition of raw emulsions and frankfurters produced with different cutters and levels of added water to different temperatures in Part II

Source[a]	d.f.	Raw emulsion				Frankfurter			
		Percent moisture	Percent fat	Percent protein	Moisture: protein ratio	Percent moisture	Percent fat	Percent protein	Moisture: protein ratio
Machine (M)	1	1.78	.001	.26	.07	17.68*	13.52*	4.39	.03
Temperature (T)	1	.46	.001	.13	.00	.89	.00	1.03	.09
Water (W)	2	163.39**	56.80*	10.93*	4.99**	104.62*	26.01*	19.84*	2.78*
M x T	1	1.34	.01	.05	.00	.002	.52	.09	.01
M x W	2	.23	1.19	1.85	.28	.30	.70	.61	.04
T x W	2	1.91	.39	3.33	.60	4.09	1.57	1.32	.11
M x T x W	2	.95	2.10	.29	.05	1.73	.94	.33	.06
Error	12	9.86	3.35	6.29	1.26	4.83	7.17	21.65	.97
Total	23	179.92	61.84	23.76	7.25	134.14	50.43	49.26	4.10

[a]Model was μ(mean) = $M_i + T_j + W_k + MxT_{ij} + MxW_{ik} + TxW_{jk} + MxTxW_{ijk} + E_{ijkl}$, where

M = Effect of machine (Hobart or Kramer-Grebe), i = 1,2
T = Effect of final emulsion temperature (7.2°C or 12.8°C), j = 1,2
W = Effect of level of added ice (2, 10, or 20%), k = 1,2,3
MxT, MxW, TxW, MxTxW = Interactions of main effects
E = Error
l = Replications 1 and 2.

*$p < .05$.

**$p < .01$.

Table A.5. Sums of squares from analysis of variance for binding characteristics of raw emulsions produced with different cutters and levels of added water to different temperatures in Part II

Source[a]	d.f.	Percent smokehouse yield	Percent fluid release[b]			Soluble[c] protein	Percent phase separation[d]			Soluble[e] protein
			Water	Fat	Total		Fat	Soluble	Insoluble	
Machine (M)	1	167.90	8.17	.21	5.77	.40	2.08	101.72	237.95	12.36
Temperature (T)	1	24.40	21.09	6.34	50.55	7.07	135.66*	15.54	158.47	115.81
Water (W)	2	82.11	10.93	3.95	12.03	2.83	9.80	399.94*	413.71	405.11
M x T	1	.27	.41	.20	.04	2.40	1.28	.55	1.79	.001
M x W	2	4.92	9.69	4.77	27.99	4.43	7.04	33.15	26.09	201.70
T x W	2	.26	1.90	1.80	3.08	8.41	2.32	2.92	2.89	43.94
M x T x W	2	10.73	3.81	2.79	11.38	.26	3.67	13.27	5.48	104.36
Error	12	46.87	27.92	11.38	87.09	60.61	33.73	477.82	920.11	792.44
Total	23	337.45	83.93	44.04	197.93	86.42	195.57	1044.35	1766.49	1675.73

[a]Model was μ(mean) = $M_i + T_j + W_k + MxT_{ij} + MxW_{ik} + TxW_{jk} + MxTxW_{ijk} + E_{ijkl}$, where

M = Effect of machine effect (Hobart or Kramer-Grebe), i = 1,2
T = Effect of final emulsion temperature (7.2°C or 12.8°C), j = 1,2
W = Effect of level of added ice (2, 10, or 20%), k = 1,2,3
MxT, MxW, TxW, MxTxW = Interactions of main effects
E = Error
l = Replications 1 and 2.

[b]Modified Rongey procedure.

[c]Measured in water released in modified Rongey procedure.

[d]Determined by centrifugation procedure.

[e]Measured in soluble phase from centrifugation procedure.

*p < .05.

**p < .01.

Table A.6. Sums of squares from analysis of variance for physical characteristics of raw emulsions produced with different cutters and levels of added water to different temperatures in Part II

Source[a]	d.f.	Frankfurter diameter	W-B shear force	Shear force/ area	Raw emulsion WHC[b]	Raw emulsion WHC[c]	Frankfurter WHC[b]	Frankfurter WHC[c]
Machine (M)	1	5.06	2.15	.0098	.024*	.016	.023	.015
Temperature (T)	1	.03	.03	.0000	.001	.006	.038	.035
Water (W)	2	6.44	3.01	.0123	.161**	.147*	.098	.171*
M x T	1	.52	.91	.0011	.000	.001	.008	.014
M x W	2	1.93	.24	.0003	.005	.002	.047	.029
T x W	2	1.23	.43	.0006	.016	.017	.012	.002
M x T x W	2	1.59	.07	.0003	.001	.002	.017	.003
Error	12	11.90	17.91	.0307	.042	.053	.104	.200
Total	23	28.69	24.75	.0553	.250	.243	.346	.468

[a]Model was $\mu(\text{mean}) = M_i + T_j + W_k + MxT_{ij} + MxW_{ik} + TxW_{jk} + MxTxW_{ijk} + E_{ijkl}$, where

M = Effect of machine (Hobart or Kramer-Grebe), i = 1,2
T = Effect of final emulsion temperature (7.2°C or 12.8°C), j = 1,2
W = Effect of level of added ice (2, 10, or 20%), k = 1,2,3
MxT, MxW, TxW, MxTxW = Interactions of main effects
E = Error
1 = Replications 1 and 2.

[b]Water-holding capacity areas determined by grid measurement.

[c]Water-holding capacity areas determined by planimeter measurement.

*$p < .05$.

**$p < .01$.

Table A.7. Sums of squares from analysis of variance for composition of MP(S)P produced by different deboners from bones of different types, ages, and species

Source[a]	d.f.	Percent composition						
		Yield	Moisture	Fat	Protein	Ash	Crude bone	Calcium
Deboner (D)	1	51,488.7**	21.13	.14	12.06**	5.76**	9.52**	1.02**
Specie (S)	1	820.6**	498.47**	543.98**	.06	.70**	1.60**	.19*
Age (A)	1	762.9*	622.44**	874.32**	2.75	.24	.62**	.23*
Type (T)	1	7.8	42.19*	9.81	.88	.93**	.06	.13
Rpm [D]	4	2,528.1**	16.86	21.13	10.03	.37	.28	.10
D x S	1	1,993.0**	2.26	1.64	12.64**	.03	1.51**	.16*
D x A	1	98.1	5.52	6.36	5.74	.61*	.24	.06
D x T	1	257.7	3.93	8.88	.29	.25	.00	.02
S x A	1	3.1	5.90	13.84	.16	.02	.02	.10
D x S x A	1	56.5	5.70	13.56	8.50*	.05	.02	.03
Error	60	6,379.4	378.11	396.31	82.58	4.25	3.10	1.92
Total	75	64,395.9	1,602.50	1,889.96	135.70	13.20	16.97	3.96

[a]Model was $\mu(\text{mean}) = D_i + S_j + A_k + T_l + \text{Rpm}[D]_{im} + DxS_{ij} + DxA_{ik} + DxT + SxA + DxSxA + E_{ijklmn}$, where

D = Effect of deboning machine (KP press or Yieldmaster), i = 1,2
S = Effect of specie (beef or pork), j = 1,2
A = Effect of bone age (mature, young, or utility), k = 1-3
T = Effect of bone type (back or blade), 1 = 1,2
Rpm[D] = Effect of speed in revolutions per minute nested within the Yieldmaster rotary deboner (300, 600, 900, 1200, or 1400 rpm), m = 1-5
DxS, DxA, DxT, SxA, DxSxA = Interactions of main effects
E = Error
n = 75 observations.

*$p < .05$.
**$p < .01$.

Table A.8. Mean values[1] and standard errors of means[2] for MP(S)P produced by a KP press deboner in Part IV

Species	Bone age	Bone type	n	Percent composition					
				Moisture	Fat	Protein	Ash	Crude bone	Calcium
Beef	Mature	Backs	3	47.42^{c}	37.93^{a}	12.17^{b}	2.05^{ab}	1.19^{b}	$.76^{a}$
	Young	Backs	3	53.93^{b}	29.96^{b}	14.05^{a}	1.90^{bc}	1.06^{b}	$.61^{ab}$
	Utility	Backs	2	44.80^{c}	39.57^{a}	13.01^{ab}	2.31^{a}	1.60^{a}	$.44^{b}$
Pork	Mature	Backs	3	53.68^{b}	31.32^{b}	11.88^{b}	2.08^{ab}	$.62^{c}$	$.50^{b}$
	Mature	Blades	2	56.83^{b}	28.92^{b}	12.36^{ab}	1.34^{d}	$.42^{c}$	$.18^{c}$
	Young	Blades	1	63.26^{a}	21.11^{c}	11.66^{b}	1.48^{cd}	$.52^{c}$	$.41^{bc}$
s.e.m.				.43	.47	.24	.05	.05	.03

[1]Means are averages of n replications. Means with the same superscript letter are not significantly different.

[2]Average standard error of means over all treatments.

Table A.9. Mean values[1] and standard errors of means[2] for composition of MP(S)P produced by the Yieldmaster rotary deboner in Part IV

Species	Bone age	Bone type	rpm	Ring	n	Percent composition					
						Moisture	Fat	Protein	Ash	Crude bone	Calcium
Beef	Mature	Backs	1200	1	3	48.33^{ef}	38.59^{ab}	11.36^{a}	1.38^{ab}	$.29^{ab}$	$.38^{ab}$
	Young	Backs	600	1	1	51.84^{cde}	34.05^{c}	11.95^{a}	1.68^{ab}	$.15^{ab}$	$.27^{ab}$
			900	1	1	58.49^{b}	26.64^{d}	12.71^{a}	1.51^{ab}	$.24^{ab}$	$.16^{b}$
			1200	2	1	49.04^{def}	35.64^{bc}	8.08^{b}	1.53^{ab}	$.33^{ab}$	$.27^{ab}$
	Utility	Backs	900	1	1	45.79^{f}	45.05^{a}	11.61^{a}	1.45^{ab}	$.21^{ab}$	$.29^{ab}$
Pork	Mature	Backs	300	2	1	53.76^{cd}	31.76^{cd}	12.49^{a}	1.31^{ab}	$.06^{b}$	$.19^{b}$
			600	2	4	53.78^{cd}	31.96^{cd}	11.99^{a}	1.29^{b}	$.12^{b}$	$.22^{b}$
			900	1	1	53.72^{cd}	32.18^{cd}	12.45^{a}	1.10^{b}	$.15^{ab}$	$.57^{a}$
			900	2	2	53.92^{bcd}	31.56^{cd}	12.08^{a}	1.25^{b}	$.11^{b}$	$.20^{b}$
			1200	1	3	53.76^{bc}	31.00^{cd}	11.78^{a}	1.70^{a}	$.48^{a}$	$.44^{ab}$
			1200	2	1	53.96^{bcd}	31.18^{cd}	12.02^{a}	1.19^{b}	$.06^{b}$	$.21^{ab}$
			1400	1	1	52.6^{cde}	33.16^{c}	12.22^{a}	1.27^{b}	$.17^{ab}$	$.29^{ab}$
	Mature	Blades	900	1	1	54.48^{bcd}	31.54^{cd}	12.48^{a}	1.06^{b}	$.19^{ab}$	$.23^{ab}$
			1200	1	2	55.08^{bc}	32.36^{c}	11.25^{a}	1.22^{b}	$.21^{ab}$	$.21^{ab}$
	Young	Blades	900	2	1	63.55^{a}	19.7^{e}	13.06^{a}	1.30^{ab}	$.17^{ab}$	$.20^{b}$
s.e.m.						.35	.35	.14	.04	.03	.03

[1]Means are averages of n replications. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of means for all treatments.

Table A.10. Sums of squares from analysis of variance for composition of the bone residue produced from the Yieldmaster rotary deboner in Part IV

Source[a]	d.f.	Percent composition				
		Moisture	Fat	Protein	Ash	Crude bone
Specie (S)	1	110.80**	42.15	45.76*	95.39**	13.71**
Age (A)	2	110.88**	701.98**	35.52	73.12**	121.49**
Type (T)	1	49.16**	427.21**	148.32**	18.65**	16.56**
Rpm (R)	4	203.16**	1,707.34**	294.26**	97.42**	152.66**
S x A[b]	1	.52	155.02**	104.27**	13.62**	11.29**
S x R[b]	2	124.76**	49.62	20.32	68.95**	55.25**
T x R[b]	1	11.76*	53.77*	1.40	.09	4.13
Error	31	73.03	379.46	205.75	28.20	40.02
Total	43	674.08	3,516.56	855.60	395.44	415.10

[a]Model was μ(mean) = $S_i + A_j + T_k + R_l + SxA_{ij} + SxR_{il} + TxR_{kl} + E_{ijklm}$, where

S = Effect of specie (beef or pork), i = 1,2
A = Effect of bone age (mature, young, utility), j = 1-3
T = Effect of bone type (back or blade), k = 1,2
R = Effect of rotary deboner speed in revolutions per minute (300, 600, 900, 1200, or 1400), l = 1-5
SxA, SxR, TxR = Interactions of main effects able to be tested
E = Error
m = 44 observations.

[b]d.f. for these interactions are less than expected due to incomplete cell design.

*$p < .05$.

**$p < .01$.

Table A.11. Mean values[1] and standard errors of means[2] for composition of bone residue produced by the Yieldmaster rotary deboner in Part IV

Species	Bone age	Bone type	rpm	Ring	n	Percent composition				
						Moisture	Fat	Protein	Ash	Crude bone
Beef	Mature	Backs	1200	1	2	50.90^{ef}	20.19^{c}	21.13^{bc}	6.13^{d}	5.18^{cde}
	Young	Backs	600	1	1	59.06^{b}	5.42^{ef}	25.09^{a}	10.10^{b}	7.22^{bc}
			900	1	1	62.40^{a}	5.58^{ef}	19.37^{c}	5.83^{d}	6.14^{bcd}
			1200	2	1	48.68^{f}	17.00^{cd}	21.99^{abc}	12.90^{a}	10.74^{a}
	Utility	Backs	900	1	1	52.73^{de}	20.81^{c}	20.48^{bc}	9.95^{b}	$.18^{i}$
Pork	Mature	Backs	300	2	1	59.28^{b}	3.81^{f}	25.29^{a}	9.77^{b}	11.34^{a}
			600	2	4	59.98^{b}	8.22^{e}	23.70^{ab}	7.18^{c}	6.65^{bc}
			900	2	2	58.95^{b}	14.54^{d}	14.61^{d}	5.19^{de}	4.34^{def}
			1200	1	3	55.42^{c}	26.07^{b}	13.12^{d}	2.62^{f}	1.62^{hi}
			1200	2	1	59.31^{b}	13.95^{d}	24.34^{a}	5.42^{de}	3.62^{efg}
			1400	1	1	51.88^{de}	31.65^{a}	13.54^{d}	2.28^{f}	1.46^{hi}
	Mature	Blades	900	1	1	54.07^{cd}	25.85^{b}	20.07^{c}	4.10^{e}	2.59^{fgh}
			1200	1	2	55.15^{c}	26.58^{b}	14.98^{d}	2.54^{f}	2.53^{gh}
	Young	Blades	900	2	1	61.19^{ab}	4.41^{ef}	23.94^{ab}	9.55^{b}	8.14^{b}
s.e.m.						.20	.35	.24	.11	.16

[1]Means are averages of n observations. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

Table A.12. Sums of squares from analysis of variance for composition of freeze-dried, extracted MP(S)P in Part IV

Source[a]	d.f.	Percent composition								
		Moisture	Fat	Protein	Ash	Ca	Mg[b]	Na	K	Fe[b]
Deboner (D)	1	1.47**	.08*	11.99	43.16**	8.91**	41.6	.06*	.19	.08
Specie (S)	1	9.63**	.02	.06	13.32**	4.45**	51.1	.07*	.01	18.28**
Age (A)	1	1.14**	.05*	3.02	.07*	.22	72.3	.00	.07	.95**
D x S	1	41.12**	.02	21.00	9.61**	2.39*	4.2	.36**	.00	.95**
D x A	1	.07	.01	3.72	.03	.13	81.0	.00	.63**	.46*
S x A	1	2.88**	.04	.60	.11**	.23	68.9	.30**	.00	2.18**
D x S x A	1	1.31**	.00	2.18	1.02**	.59	185.0*	.02	.47**	.01
Error	8	.12	.07	83.98	.07	2.55	174.0	.07	.32	.38
Total	15	57.73	.28	126.54	67.40	19.47	678.0	.88	1.68	23.26

[a]Model was μ(mean) = $D_i + S_j + A_k + DxS_{ij} + DxA_{ik} + SxA_{jk} + DxSxA_{ijk} + E_{ijkl}$, where

D = Effect of deboning machine (KP press or Yieldmaster), i = 1,2
S = Effect of specie bone type (beef back or pork blade), j = 1,2
A = Effect of bone age (mature or young), k = 1,2
DxS, DxA, SxA, DxSxA = Interactions of main effects
E = Error
k = Observations 1 and 2

[b]Sum of squares are given times 10^{-4}.

*p < .05.

**p < .01.

Table A.13. Mean values[1] and standard errors of means[2] for composition of freeze-dried, extracted MP(S)P in Part IV

Deboner	Species[4]	Age	Percent composition[3]								
			Moisture	Fat	Protein	Ash	Ca	Mg	Na	K	Fe
KP press	Beef	Mature	1.73^{e}	$.47^{a}$	83.55^{a}	13.50^{a}	4.50^{a}	$.29^{a}$	1.11^{a}	1.11^{cd}	$.056^{a}$
		Young	$.79^{f}$	$.30^{ab}$	84.26^{a}	13.20^{b}	4.70^{a}	$.23^{abc}$	$.93^{ab}$	1.98^{a}	$.040^{c}$
	Pork	Mature	6.21^{a}	$.22^{bc}$	80.25^{a}	9.78^{c}	2.82^{b}	$.27^{ab}$	$.48^{d}$	1.41^{bcd}	$.022^{e}$
		Young	5.82^{b}	$.25^{abc}$	83.21^{a}	10.17^{d}	2.72^{b}	$.16^{bc}$	$.70^{c}$	1.60^{abc}	$.022^{e}$
Yield-master	Beef	Mature	5.98^{ab}	$.30^{ab}$	83.22^{a}	8.07^{g}	2.44^{b}	$.27^{ab}$	$.76^{bc}$	1.64^{ab}	$.046^{b}$
		Young	4.16^{c}	$.05^{c}$	83.47^{a}	8.96^{e}	2.23^{b}	$.17^{bc}$	$.44^{d}$	1.03^{d}	$.038^{c}$
	Pork	Mature	2.91^{d}	$.30^{ab}$	85.98^{a}	8.46^{f}	1.53^{b}	$.14^{c}$	$.58^{cd}$	1.24^{bcd}	$.023^{e}$
		Young	3.92^{c}	$.15^{bc}$	85.53^{a}	8.02^{g}	2.57^{b}	$.25^{abc}$	$.96^{ab}$	1.31^{bcd}	$.028^{d}$
s.e.m.			.09	.07	2.29	.07	.40	.03	.06	.14	.0015

[1]Means are averages of two observations. Means for each component with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

[3]Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, Fe = iron.

[4]Beef back and pork blade bones were compared.

Table A.14. Mean values[1] and standard errors of means[2] for weight of rats in Part IV

Diet group	Weight at each time interval (g)						
	Day 0	Day 5	Day 10	Day 15	Day 20	Day 25	Day 28
Control (casein)	44.59^{a}	50.78^{bcd}	63.03^{c}	77.96^{b}	90.92^{b}	110.09^{c}	112.41^{c}
KP press							
Mature beef	45.06^{a}	45.45^{e}	43.96^{e}	42.74^{d}	42.56^{d}	43.75^{f}	42.02^{f}
Young beef	43.80^{a}	46.75^{de}	46.38^{de}	46.76^{cd}	49.81^{cd}	55.45^{e}	55.12^{e}
Mature pork	44.85^{a}	49.83^{cde}	62.10^{c}	75.73^{b}	100.06^{b}	123.44^{b}	134.64^{b}
Young pork	45.25^{a}	55.82^{a}	68.78^{b}	79.37^{b}	91.55^{b}	117.48^{bc}	125.38^{b}
Yieldmaster deboner							
Mature beef	44.85^{a}	48.10^{de}	51.40^{d}	53.79^{c}	59.42^{c}	72.58^{d}	76.44^{d}
Young beef	45.21^{a}	47.93^{de}	49.66^{de}	52.02^{c}	54.60^{c}	73.26^{d}	72.4^{d}
Mature pork	44.57^{a}	53.66^{abc}	75.70^{a}	98.49^{a}	116.50^{a}	139.08^{a}	150.00^{a}
Young pork	44.76^{a}	54.68^{ab}	77.82^{a}	102.58^{a}	118.65^{a}	145.21^{a}	157.80^{a}
s.e.m.	1.31	1.56	2.02	2.68	3.28	4.00	4.08

[1]Means are averages for 10 rats. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

Table A.15. Mean values[1] and standard errors of means[2] for amount of feed[3] consumed by the rats in Part IV

Diet group	Feed consumer at each time interval (g)						
	Day 5	Day 10	Day 15	Day 20	Day 25	Day 28	Total
Control (casein)	26.68^{bc}	36.04^{c}	45.26^{c}	55.71^{c}	61.55^{cd}	37.79^{c}	263.1^{c}
KP press							
Mature beef	23.67^{c}	22.65^{e}	25.65^{e}	23.00^{f}	22.90^{f}	14.87^{f}	132.7^{e}
Young beef	23.69^{c}	26.55^{de}	28.87^{de}	29.24^{ef}	29.49^{f}	20.60^{e}	158.4^{e}
Mature pork	26.80^{bc}	41.92^{b}	55.60^{b}	66.19^{b}	71.67^{b}	52.50^{a}	314.7^{b}
Young pork	32.33^{a}	40.95^{bc}	48.99^{c}	55.71^{c}	69.18^{bc}	46.43^{b}	293.6^{b}
Yieldmaster deboner							
Mature beef	26.62^{bc}	29.05^{d}	32.66^{d}	37.40^{d}	46.40^{e}	29.00^{d}	201.1^{d}
Young beef	26.71^{bc}	28.95^{c}	33.30^{d}	34.59^{de}	53.97^{de}	25.53^{de}	203.0^{d}
Mature pork	28.26^{b}	52.88^{a}	65.90^{a}	78.87^{a}	82.02^{a}	54.42^{a}	362.4^{a}
Young pork	29.16^{ab}	54.54^{a}	68.69^{a}	73.25^{ab}	85.36^{a}	56.23^{a}	367.2^{a}
s.e.m.	.42	.62	.69	.81	.99	.55	3.07

[1]Means are averages for 10 rats. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

[3]Feed was comprised of 10 percent protein, 5 percent corn oil, 5 percent vitamin and mineral premixes, and the remainder sucrose.

Table A.16. Mean values[1] and standard errors of means[2] for protein efficiency ratios[3] of rats in Part IV

Diet group	Protein efficiency ratio[3]					
	Day 5	Day 10	Day 15	Day 20	Day 25	Day 28
Control (casein)	2.26^{b}	2.81^{b}	3.06^{b}	2.81^{b}	2.89^{a}	2.56^{c}
KP press						
Mature beef	.18^{d}	-.25^{e}	-.34^{f}	-.27^{e}	-.09^{d}	-.23^{f}
Young beef	1.13^{c}	.47^{d}	.35^{e}	.52^{d}	.80^{c}	.69^{e}
Mature pork	1.82^{bc}	2.48^{b}	2.46^{c}	2.89^{ab}	2.99^{a}	2.84^{ab}
Young pork	3.22^{a}	3.13^{b}	2.75^{bc}	2.59^{b}	2.96^{a}	2.73^{bc}
Yieldmaster deboner						
Mature beef	1.19^{c}	1.14^{c}	.99^{d}	1.15^{c}	1.63^{b}	1.57^{d}
Young beef	1.02^{cd}	.73^{cd}	.72de	.73^{d}	1.56^{b}	1.33^{d}
Mature pork	3.16^{a}	3.83^{a}	3.78^{a}	3.18^{a}	3.07^{a}	2.91^{ab}
Young pork	3.39^{a}	3.93^{a}	3.67^{a}	3.24^{a}	3.20^{a}	3.06^{a}
s.e.m.	.30	.22	.18	.12	.13	.08

[1]Means are averages for 10 rats. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

[3]Protein efficiency ratio (PER) = $\frac{\text{weight gain of rats}}{\text{weight of protein consumed}}$.

Table A.17. Mean values[1] and standard errors of means[2] for relative PER ratio[3] of rats in Part IV

Diet group	Relative PER ratio					
	Day 5	Day 10	Day 15	Day 20	Day 25	Day 28
Control (casein)	100.0^{b}	100.0^{b}	100.00^{b}	100.0^{b}	100.0^{a}	100.0^{c}
KP press						
Mature beef	8.07^{d}	-9.07^{e}	-11.13^{f}	-9.70^{e}	-3.25^{d}	-8.85^{f}
Young beef	50.01^{c}	16.83^{d}	11.52^{e}	18.67^{d}	27.72^{c}	27.13^{e}
Mature pork	80.67^{bc}	88.45^{b}	80.31^{c}	102.84^{ab}	103.70^{a}	111.24^{ab}
Young pork	142.42^{a}	111.48^{b}	89.94^{bc}	92.38^{b}	102.58^{a}	106.65^{bc}
Yieldmaster deboner						
Mature beef	52.64^{c}	40.77^{c}	32.44^{d}	40.81^{c}	56.49^{b}	61.33^{d}
Young beef	45.06^{c}	25.87^{cd}	23.55^{de}	25.98^{d}	54.13^{b}	52.14^{d}
Mature pork	139.94^{a}	136.42^{a}	119.79^{a}	113.31^{a}	106.39^{a}	113.83^{ab}
Young pork	149.87^{a}	139.95^{a}	123.41^{a}	115.31^{a}	111.05^{a}	119.84^{a}
s.e.m.	13.05	7.91	5.94	4.29	4.38	3.31

[1]Means are averages for 10 rats. Means with the same superscript letter are not significantly different ($p < .05$).

[2]Average standard error of mean for all treatments.

[3]Relative PER ratio = $\frac{\text{protein efficiency ratio of treatment group}}{\text{protein efficiency ratio of casein group}} \times 100$ at each time interval.

Table A.18. Sums of squares from analysis of variance for initial weight, total weight gain, total feed consumed, and 28 day PER[a] and relative PER ratio[b] as influenced by cage position

Source[c]	d.f.	Initial weight (g)	Total weight gain (g)	Total feed consumed (g)	28 day PER	28 day relative PER ratio
Tier (T)	2	7.29	250.85	18.96	.82	1,256.45
Row (R)	4	970.51**	804.10	92.30	.65	998.05
Column (C)	5	16.08	20,493.87	869.21	12.86	19,681.69
T x R	8	55.59	6,860.69	242.25	5.93	9,071.49
T x C	10	55.62	27,688.61	1,366.04	18.78	28,748.80
R x C	20	73.39	27,530.60	1,125.92	24.04	36,802.93
Error	40	221.20	72,013.39	2,958.30	50.40	77,146.28
Total	89	1,399.68	155,642.11	6,672.98	113.48	173,705.68

[a]PER = protein efficiency ratio = weight gain of rats/weight of protein consumer.

[b]Relative PER ratio = PER of treatment group/PER of casein group x 100.

[c]Model was μ(mean) = $T_i + R_j + C_k + TxR_{ij} + TxC_{ik} + RxC_{jk} + E_{ijkl}$, where

T = Effect of tier location of cage, i = 1-3
R = Effect of row location of cage, j = 1-5
C = Effect of column location of cage, k = 1-6
TxR, TxC, RxC = Interactions of main effects
E = Error
1 = 1 to 10 observations.

*p <.05.

**p <.01.

Table A.19. Sums of squares from analysis of variance for initial weight, total weight gain, total feed consumed, and 28 day PER[a] and relative PER ratio[b] as influenced by diet consumed

Source[c]	d.f.	Initial weight (g)	Total weight gain (g)	Total feed consumed	28 day PER	28 day relative PER ratio
Deboner (D)	2	.62	13,315.74**	693.50**	14.32**	21,917.90**
Age (A)	2	.51	1,133.00*	8.72	4.91**	7,521.71**
Specie (S)	2	.70	129,527.58**	5,167.32**	87.79**	134,382.97**
D x A x S	2	13.67	296.45	41.67	.66*	1,012.35*
Error	81	1,384.18	11,365.83	761.77	5.80	8,870.76
Total	89	1,399.68	155,642.11	6,672.98	113.48	173,705.68

[a]PER = protein efficiency ratio = weight gain of rats/weight of protein consumed.

[b]Relative PER ratio = PER of treatment group/PER of casein group x 100.

[c]Model was μ(mean) = $D_i + A_j + S_k + DxAxS_{ijk} + E_{ijkl}$, where

D = Effect of deboning machine (KP press, Yieldmaster, or casein control diet), i = 1-3
A = Effect of bone age (mature, young, or casein control diet), j = 1-3
S = Effect of specie (beef, pork, or casein control diet), k = 1-3
DxAxS = Interaction of main effects
E = Error
1 = 1 to 10 observations.

*$p < .05$.

**$p < .01$.